TECHNICAL REPORT

TS-136

MASS, PERMEABILITY, AND THICKNESS CHANGES IN ABRADED FABRICS

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Lowell Technological Institute

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U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

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FOREWORD

This report is one in a continuing series on wear resistance issued by the U.S. Army Natick Laboratories. Army research on the wear resistance of textiles was initiated early in World War II, when problems in the supply and distribution of clothing made it apparent that improvements in logistic support as well as monetary savings could be realized by extending the service life of clothing. The complexity of textile wear phenomena has stimulated many investigations of wear mechanisms. These investigations have led to significant advances in the wear performance of many types of military textiles and have made more meaningful the difficult task of interpreting laboratory and field wear data.

The work upon which this report is based sheds light on the role of fiber debris in laboratory abrasion testing. The fact that fiber debris may be retained by fabrics during abrasion has a bearing on the selection of parameters to characterize the abrasion process. This approach can be extended to practical wear situations and can increase the understanding of factors governing wear rates.

The authors wish to acknowledge the support and contributions of members of the staff of the Lowell Technological Institute, where portions of this work were done. They are especially indebted to Professor John J. McDonald, Head of the Department of Textile Technology and to Professor David H. Pfister.

Dr. George R. Thomas, Associate Director of the Clothing and Organic Materials Division of the Army Natick Laboratories, furnished encouragement and guidance throughout all of the experimental and analytical phases of this study. Mr. Clarence J. Pope conducted tests on garments worn in the field and data from these were used in this report. Mr. Jesse E. Johnston, Jr. of Spartanburg, S.C., provided valuable suggestions on techniques. Tracerlab Inc., Waltham, Mass., has permitted the inclusion in this report of data from tests on their Beta Gauge.

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ABSTRACT

This report presents the changes that take place in mass, permeability, and thickness during the abrasion of textile fabrics. Changes in permeability are shown to be influenced by the extent to which the abraded fabric will retain fiber debris during the course of the abrasion. While the permeability of a cotton oxford fabric decreases continuously and significantly up to the point of hole formation, the permeability of a sateen fabric increases during abrasion, an effect which is normally expected as a result of breakdown in the yarn structure. The extent to which the fiber debris is retained by the fabric is a function of the rate of loss of mass. Thickness decreases are a function more of the type of abrader than of the type of fabric. Changes in permeability as well as in thickness are not simple functions of the degree of abrasion of all fabric types; they must be viewed in terms of the response of specific fabrics to specific types of abrasive action.

MASS, PERMEABILITY, AND THICKNESS CHANGES IN ABRADED FABRICS

INTRODUCTION

The course of abrasion in textile fabrics is often evaluated by noting the changes in certain physical properties that are capable of objective measurement (mass, strength, thickness, capacitance, porosity to light or air, etc.).

Crawshaw, Morton, and Brown (1), working with mass and strength changes, observed that the curve for mass-loss-versus-abrasion rises gradually at first but more rapidly toward the end of the test. This is in contrast to the strength-loss curve, which rises rapidly at first. Koch, Satlow, and Bobeth (2), also working with changes in mass, used a KS factor to characterize the abrasion resistance of fabrics in terms of weight loss. "KS" is the ratio of the total average weight loss at each stage of abrasion to the total number of abrasion strokes at each stage.

Schiefer (3) characterized the abrasion of textile fabrics by their capacitance coefficient and porosity. He defined the coefficient "Q" as the ratio of the difference in capacitance between the abraded and unabraded specimens to the difference in capacitance between the unabraded specimen and air. In comparative tests of two fabrics, he found good agreement between this coefficient and the percentage of increase in air permeability. The air permeability of both fabrics increased rapidly with the number of cycles of abrasion. Pfister (4) observed that the permeability of some fabrics increases with abrasion while it decreases for others.

Hoffman and Backer (5), using breaking strength as a criterion of combat course and laboratory wear, observed a significant correlation between visual wear scores and the percentage of fabric strength loss.

Lee and Finkner (6), in a practical wear trial of worsted garments, found significant inverse linear relationships between hours of wear and thickness, capacitance, and weight.

As far as could be determined from examining the literature, previous work that used changes in measurable physical properties for evaluating the abrasion of textiles had one of two objectives: the determination of a wear index based on the rate of the change in these properties; or the development of an objectively measurable end point.

The purposes of this study were to examine the changes in permeability, thickness, and mass that take place in fabrics during abrasion in terms of fabric and machine differences, and to use the permeability measurement as a sensitive means for determining what happens to fiber debris during the abrading process. Changes in the mass of an abraded fabric are difficult

to evaluate directly since, as observed by Crawshaw, Morton, and Brown (1), the losses can be relatively small for significantly large amounts of abrasion and, in the critical initial stages of abrasion, the magnitude of the measuring error is sufficient to mask the full amount of loss.

While it is not possible to directly equate changes in air permeability with changes in mass during abrasion, changes in permeability can indirectly indicate the manner in which the worn mass of fibers distributes itself between the textile structure and the environment. During testing, the loose fibers that are abraded from the fabric may be disposed of in several ways. The fibers may be completely brushed away or they may be dispersed by vacuum, depending on the nature of the test. This fiber loss results in a progressive increase in the permeability of the fabric as abrasion proceeds. On the other hand, some of the fibers may be "ground into" the fabric interstices. In this case, there is no change in permeability as an equilibrium is established between the loss and gain of fibers. This equilibrium is recognized in the permeability-versus-abrasion curve as an induction period that extends up to that point where gross fabric destruction begins. The fibers may be ground into the base fabric structure at such a rapid rate that there will be a continuing decrease in air permeability up to the moment of gross destruction. The exact mechanism of worn fiber disposal will depend upon such factors as the nature of the fabric structure, the fiber composition, the finish, the type of abrasive action, and the handling of the fabric during the abrasion process (brushing, vacuuming, or laundering). If, then, the manner in which the fabric accepts or rejects fiber debris influences its rate of wear, it is important to standardize the test conditions so that they will more closely correspond to the wear that is encountered in the field.

The tests used to obtain the data here presented are described in the following section.

EXPERIMENTAL PROCEDURE

1. Materials

Tests were limited to two types of fabric which had been found to respond differently to abrasion in terms of permeability changes. One was an 8.8 oz/yd^2 carded sateen (7) and the other a 5.5 oz/yd^2 Type VI combed oxford (8). The cover factor sum of these two fabrics was 41.2 and 47.0. The tightness of the sateen was 71% of maximum, whereas the oxford was 100%.*

2. Equipment

Tests were made on the Taber and Stoll abraders as representative of two basic types of abrasive action (9). Individual specimens of

* See Appendix A

the fabrics were abraded under standard conditions (65% R.H. and 70 degrees F.) in steps of 25, 50, 100, or 300 cycles until the end-points of the tests were reached. The end-point on the Taber abrader was selected by the appearance of two small holes in separate areas of the specimen. Since the desired measurements could not be made on the Stoll specimens after rupture had occurred (rupture being the conventional end-point), for computational purposes the end-point was taken as the highest number of cycles obtained in the appropriate step range used, prior to failure. Thus, in Stoll tests of the sateen, steps of 300 cycles were used toward the end of the test. The sample at 2400 cycles was intact, but the final specimen did not reach 2700 cycles before rupture occurred. Therefore, 2400 cycles was considered to be the end-point. The sateen was abraded on the filling-face since this side is normally worn to the outside of most garments in which this fabric is used. Taber samples were lightly brushed every two minutes.

Measurements were made of air permeability, thickness, and mass in the abraded areas of all of the specimens. The Gurley Densometer (10) was used for the air permeability measurements. The clamping plates of the Gurley have circular orifices of 0.1 in^2 in area, which is equivalent to a diameter of just under 0.36 inches. Two thin metal plates, having coaxial circular holes approximately 0.50 inches in diameter, were used to hold the abraded specimens so that the area for measurement could be exactly positioned between the clamping plates of the Gurley. Gurley seconds (300 cc) were converted to $ft^3/min/ft^2$ using the equation of Landsberg and Winston (11)*.

A Randall-Stickney gauge (12) having a presser foot with a diameter of 0.375 inches under a load of 6 oz. was used for the thickness measurements.

Mass measurements were obtained by punching out small segments of fabric in the abraded area using a circular die having a diameter of 0.375 inches. Mass measurements were made after the permeability and thickness measurements, since the mass test is destructive. Mass values were converted to mg/cm^2.

For tests on the Taber, measurements of physical properties were made at 4 positions at 90^o intervals at the intersection of diameters running from the center of the specimen, parallel to the warp and filling yarns, within the annulus formed by the abraded path. For the Stoll tests, the average of two measurements within the abraded path was reported since, in this case, the abrasive action was unidirectional (warp direction only).

For the Taber tests, where four separate positions on each specimen were analyzed, each individual result was considered in terms of position around the annulus; and the average result was analyzed in terms

* See Appendix B

of changes with cycles of abrasion. In the Stoll tests, only changes with cycles of abrasion are reported since the abrasion was unidirectional and the abraded areas were so small that variations across the width of the specimens could not be measured.

Mass, permeability, and thickness changes are reported as a function of cycles of abrasion for the Taber and the Stoll, and for the two fabrics tested. These same physical properties are reported as a function of position on the Taber for the two fabrics. Data are presented on permeability changes arising from vacuuming, laundering, and fabric face to back testing. In addition, a certain amount of data are given on mass, permeability, and thickness changes in fabrics which had been worn as garments on the Army's accelerated "Cotton" wear course (13) at Ft. Lee, Virginia.

RESULTS AND DISCUSSION

The results of the tests are shown in Tables I to IV inclusive. Figures 1 to 3 inclusive are plots of the percent change in the parameter measured versus the percent of cycles to ultimate failure of the fabric (conversion tables in Appendix C).

1. Mass Changes

In view of the small size of the specimen upon which the mass measurement was made as well as the general variability associated with abrasion measurements, there is appreciable scatter in the mass change plots shown in Figure 1. The oxford fabric reached its end-point before it had lost 10% of its mass. The sateen reached its end-point by the time it had lost 25% of its mass. These relative mass changes appear to be independent of the type of abrasive action. In the initial stages of abrasion the oxford shows little change in mass. This could arise from the fact that either very little actual abrasion occurred during the initial stages of wear, or if such abrasion did occur the fiber debris produced was retained by the fabric and did not result in a decrease in mass. The fact that a decrease in air permeability occurred (see next paragraph) during the initial stage of wear favors the fiber retention hypothesis. The conditions under which the fabric was abraded (1000 grams for the Taber; 4 lbs tension and 1 lb pressure for the Stoll) would be insufficient to account for the decrease in permeability. In fact, a pressure of 1000 psi applied to the fabric by a Carver press, decreased the permeability of the oxford by less than 20%, whereas permeability decreases during abrasion were as high as 70%.

Loss of mass was more rapid in the case of the sateen; differences between the Taber and Stoll abraders were greater for the sateen. For tests made using the Stoll there was an immediate and continuing drop in mass of the sateen at a rapid rate. In the Taber tests there was

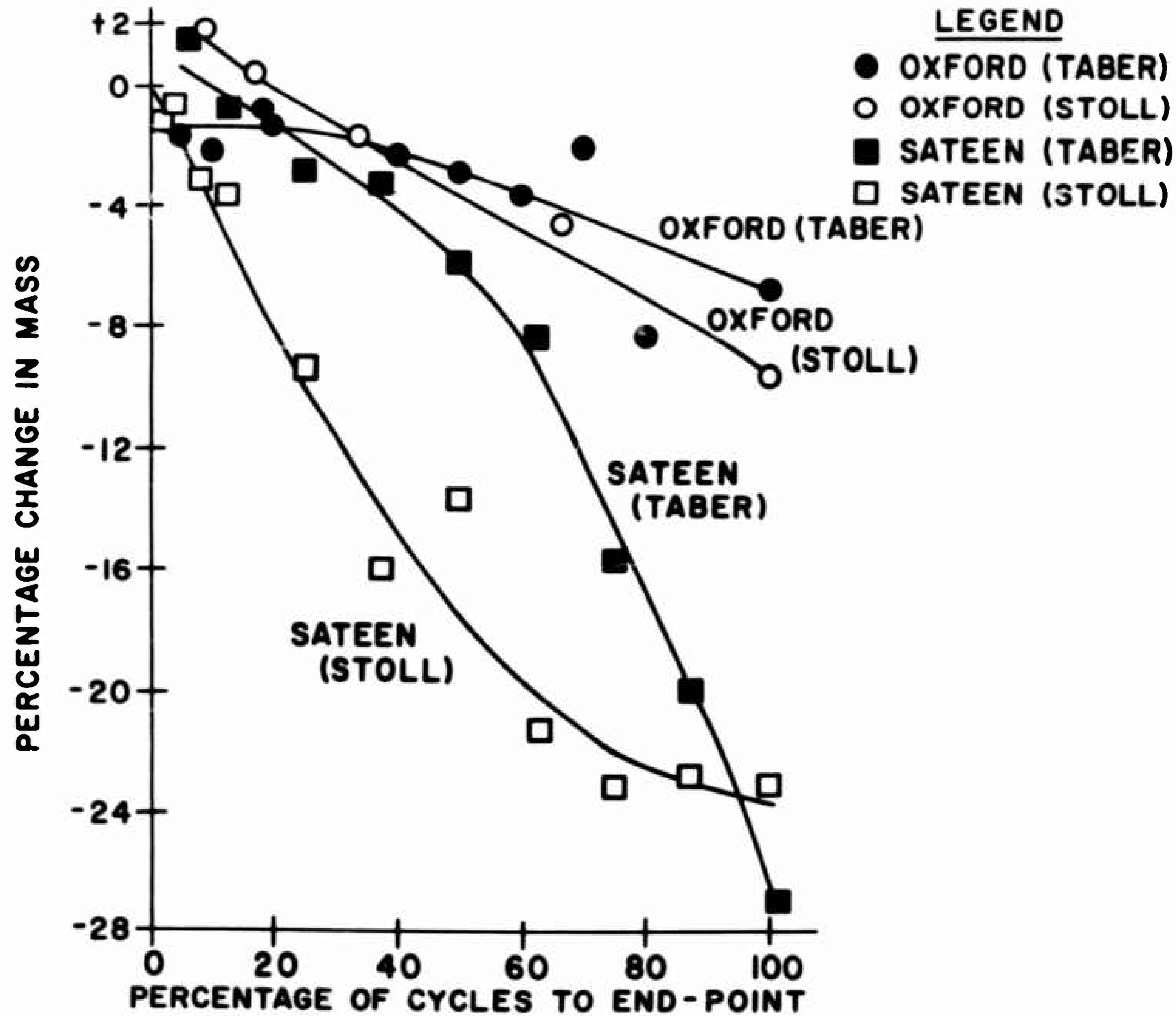

Figure 1. Mass Changes in Sateen and Oxford Fabrics During Abrasion on Taber and Stoll Testers

TABLE I

Mass Changes in Sateen and Oxford Fabrics During Abrasion on Taber and Stoll Testers

Cycles of Abrasion	TABER Mass (mg/cm^2) Sat	TABER Mass (mg/cm^2) Oxf	TABER Change in Mass* (%) Sat	TABER Change in Mass* (%) Oxf	STOLL Mass (mg/cm^2) Sat	STOLL Mass (mg/cm^2) Oxf	STOLL Change in Mass* (%) Sat	STOLL Change in Mass* (%) Oxf
0	28.4	19.2	--	--	29.5	19.6	--	--
25	28.8	18.8	+ 1.5	-1.7				
50	28.2	18.8	- .7	-2.1	29.1	20.0	- 1.2	+1.9
75	28.1		- .8					
100	27.6	19.0	- 2.7	-1.3	29.3	19.7	- .7	+ .5
150	27.5		- 3.2					
200	26.7	18.8	- 6.0	-2.2	28.6	19.3	- 3.1	-1.7
250	26.0	18.7	- 8.3	-2.8				
300	23.9	18.5	-15.7	-3.7	28.4	18.3	- 3.6	-6.7
350	23.0	18.8	-18.8	-2.1				
400	20.7	17.6	-26.9	-8.3		18.7		-4.5
500		17.9		-6.8				
600					26.7	17.7	- 9.3	-9.6
900					24.8		-16.0	
1200					25.5		-13.6	
1500					23.2		-21.2	
1800					22.6		-23.1	
2100					22.8		-22.7	
2400					22.6		-23.1	

* + sign indicates increase in mass
- sign indicates decrease in mass

a slight induction period in the mass change vs. abrasion change curve for the sateen, not as extensive as for the oxford, but then the rate of drop proceeded rapidly as in the Stoll tests. If the deposition hypothesis is valid, it would be expected that the changes in mass would bear an inverse relationship to the changes in permeability, i.e., a decrease in mass should be reflected in an increase in permeability. Also, no change in mass could mean a decrease in permeability as a result of clogging of the fabric interstices.

2. Permeability Changes

Examination of Figure 2 reveals that the order of the curves along the ordinate axis is the reverse of the order of the relative mass changes in Figure 1. For the sateen tests on the Stoll (Fig. 2), there was a progressive increase in the air permeability with no apparent induction period. This behavior is in accordance with the mass changes observed for the sateen fabric, namely a rapid decrease in mass with no induction period. For the sateen evaluated on the Taber Abrader there was a long induction period extending to approximately 50% of the ultimate wear life before air permeability began to increase. This corresponds to the mass changes in Figure 1 where there was a slight induction period before the mass began to drop but then it continued to drop at a rapid rate. The small proportion of abraded fiber that was not removed in brushing was apparently sufficient to compensate for the fibers lost to the fabric structure and as a result the permeability remained relatively unchanged up to about 60% of the ultimate wear life. The oxford fabric showed a decrease in permeability when evaluated on the Stoll or Taber abraders. For the tests made using the Stoll the decrease took place most rapidly during the initial stages of abrasion and then showed only slight additional changes up to the end point of the test. In the Taber tests, the initial changes were even more rapid and continued at a fairly rapid rate, beginning to level off only at about 40% of the ultimate wear life. In the Taber tests, for both the sateen and oxford, there was more of a tendency for clogging to take place as evidenced by a smaller rate of increase of permeability in the sateen and a larger rate of decrease of permeability in the oxford. These trends correspond to the findings on mass changes where slightly less mass was lost by the fabrics abraded on the Taber.

3. Thickness Changes

Thickness changes appeared to be a function more of the type of instrument than fabric. For example, the two fabrics showed a slower rate of decrease in mass in the Taber tests than the same two fabrics evaluated on the Stoll (Fig. 3). In the Stoll tests, the rate of change of thickness with relative cycles of ultimate abrasion was rather constant for the two fabrics until 30% of the ultimate wear life, after which the sateen continued to decrease in thickness at a rather rapid rate, whereas the oxford leveled off at a constant value. It is interesting to note that the sateen increased in thickness close to the end-point as a result of fuzzing of the fabric's surface. This effect was not noted for tests on the Taber abrader. The greater force per

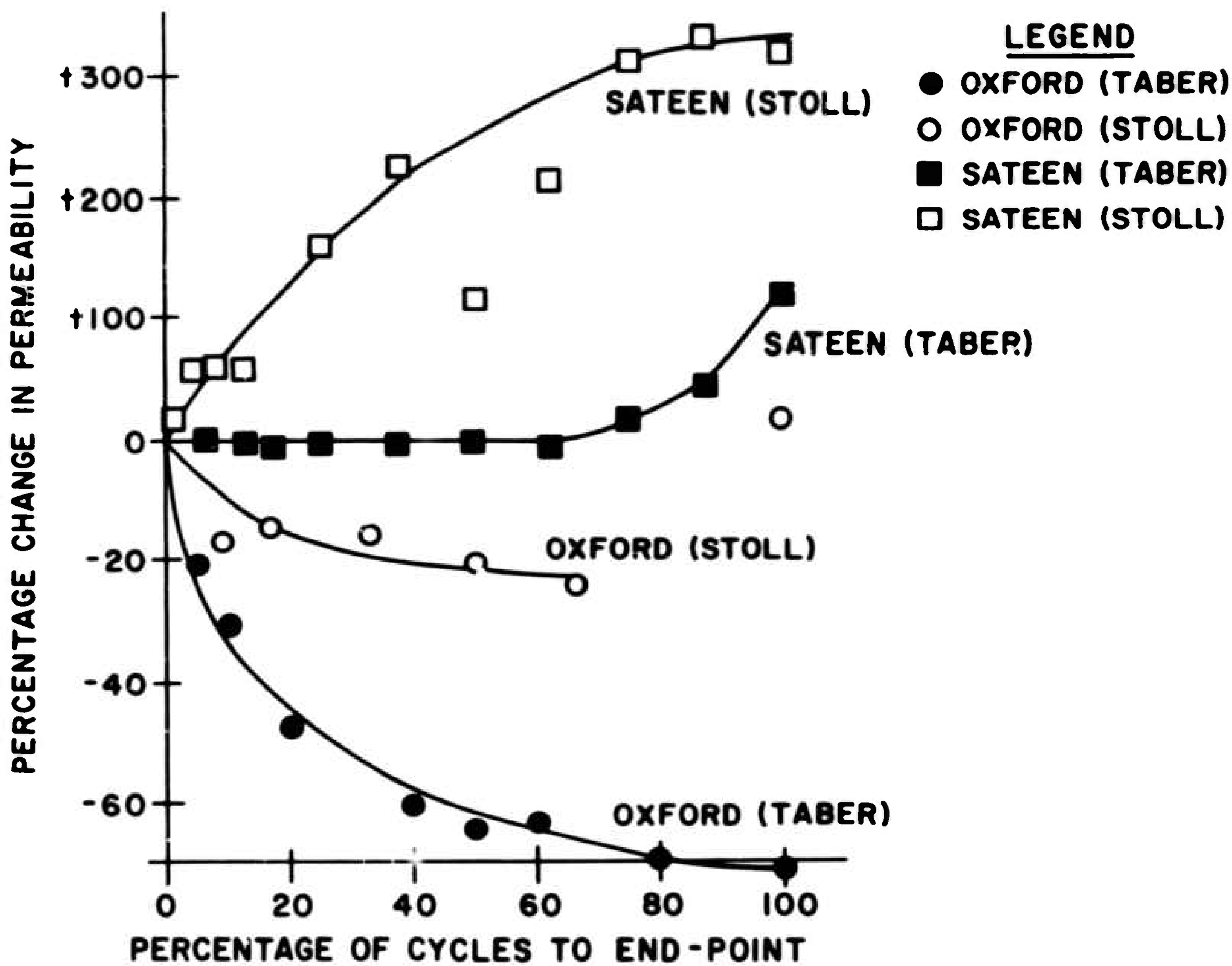

Figure 2. Permeability Changes in Sateen and Oxford Fabrics During Abrasion on Taber and Stoll Testers

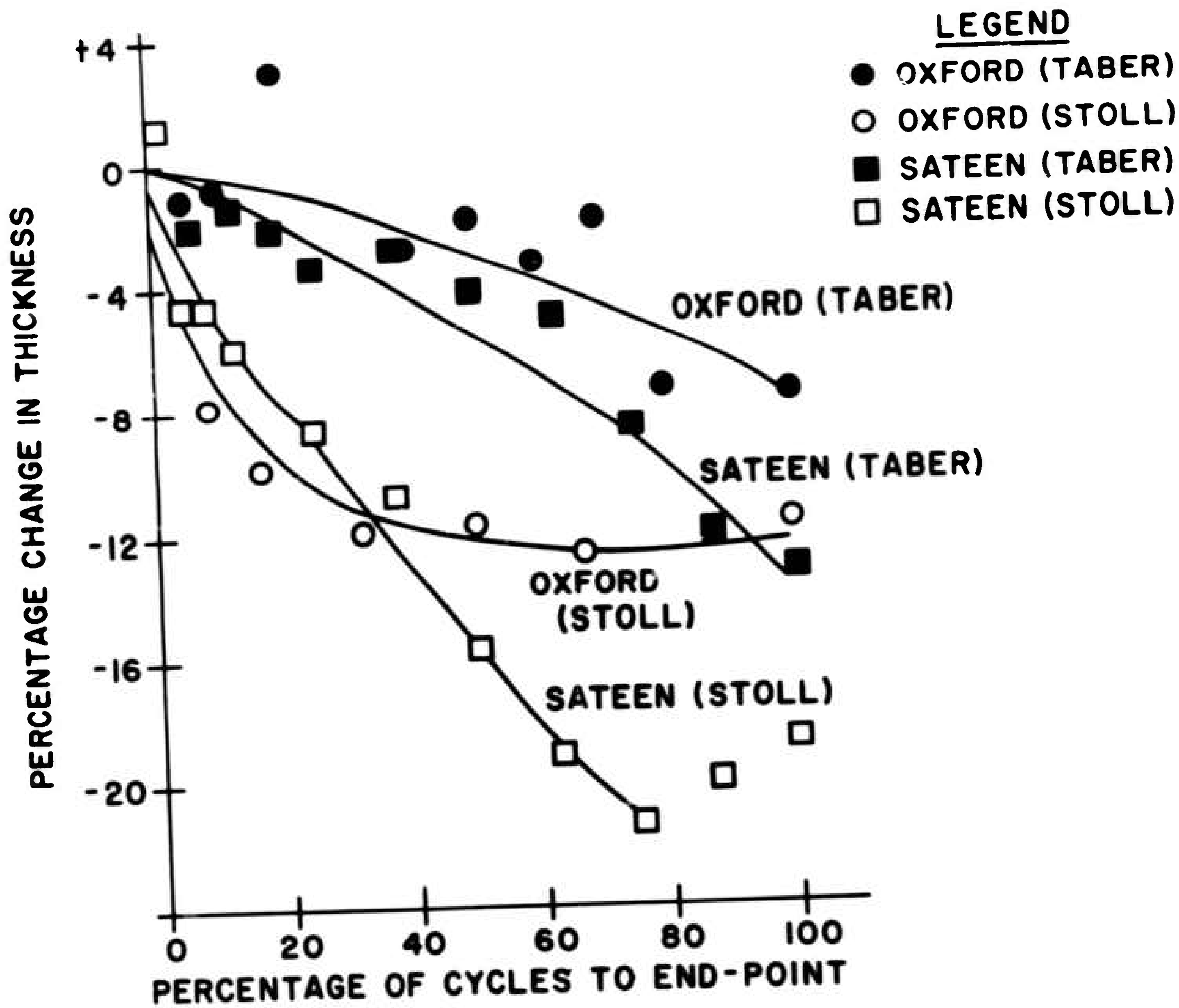

Figure 3. Thickness Changes in Sateen and Oxford Fabrics During Abrasion on Taber and Stoll Testers

TABLE II

Air Permeability Changes in Sateen and Oxford Fabrics During Stoll Abrasion

Cycles of Abrasion	Gurley Seconds (300 cc)		Air Perm. $ft^3/min/ft^2$		Change in Air Perm* %	
	Sat	Oxf	Sat	Oxf	Sat	Oxf
0	31.3	167.1	29.4	5.5	--	--
50	27.0	200.4	34.0	4.6	+15.8	-16.6
100	19.7	195.0	46.6	4.7	+58.9	-14.3
200	19.6	198.0	46.9	4.6	+59.9	-15.6
300	19.7	210.0	46.6	4.4	+58.9	-20.4
400		220.5		4.2		-24.2
600	12.1	160.5	75.7	5.7	+158.0	+ 4.1
900	9.6		95.6		+225.7	
1200	14.5		63.2		+115.3	
1500	10.0		92.1		+213.9	
1800	7.6		121.4		+313.6	
2100	7.2		127.5		+334.3	
2400	7.4		123.3		+320.3	

* + sign indicates increase in air permeability
- sign indicates decrease in air permeability

TABLE III

Air Permeability Changes in Sateen and Oxford Fabrics During Taber Abrasion

Cycles of Abrasion	Gurley Seconds (300 cc)		Air Perm. $ft^3/min/ft^2$		Change in Air Perm* %	
	Sat	Oxf	Sat	Oxf	Sat	Oxf
0	32.7	133.6	28.1	6.9	--	--
25	32.2	168.8	28.5	5.4	+ 1.8	-20.8
50	33.9	192.4	27.1	4.8	- 3.4	-30.6
75	35.9		25.6		- 8.7	
100	33.7	254.5	27.2	3.6	- 2.9	-47.5
150	34.6		26.5		- 5.4	
200	33.0	343.2	27.8	2.7	- .8	-61.1
250	35.8	384.8	25.6	2.4	- 8.6	-65.3
300	27.9	365.6	32.9	2.5	+17.5	-63.5
350	22.4		41.1		+46.5	
400	14.9	446.3	61.8	2.1	+120.5	-70.1
500		479.3		1.9		-72.1

* + sign indicates increase in air permeability
- sign indicates decrease in air permeability

TABLE IV

Thickness Changes in Sateen and Oxford Fabrics During Abrasion on Taber and Stoll Testers

Cycles of Abrasion	TABER Average Thickness (mils) Sat	TABER Average Thickness (mils) Oxf	TABER Change in Thickness* (%) Sat	TABER Change in Thickness* (%) Oxf	STOLL Average Thickness (mils) Sat	STOLL Average Thickness (mils) Oxf	STOLL Change in Thickness* (%) Sat	STOLL Change in Thickness* (%) Oxf
0	21.9	10.4	--	--	22.5	10.1	--	--
25	21.5	10.3	- 2.0	-1.1				
50	21.6	10.3	- 1.4	- .9	22.8	9.3	+ 1.2	- 7.8
75	21.4		- 2.2					
100	21.1	10.7	- 3.4	+3.0	21.5	9.1	- 4.6	- 9.8
150	21.3		- 2.8					
200	20.9	10.1	- 4.2	-2.8	21.5	8.9	- 4.6	-11.8
250	20.8	10.2	- 5.0	-1.9				
300	19.9	10.0	- 8.6	-3.3	21.2	8.9	- 5.9	-11.7
350	19.2	10.2	-12.1	-1.9				
400	18.9	9.6	-13.2	-7.4		8.8		-12.7
500		9.6		-7.6				
600					20.6	8.9	- 8.6	-11.7
900					20.1		-10.8	
1200					19.0		-15.7	
1500					18.2		-19.2	
1800					17.7		-21.4	
2100					18.0		-20.1	
2400					18.3		-18.8	

* + sign indicates increase in thickness
  - sign indicates decrease in thickness

unit area characteristic of the Stoll test may be a possible explanation of the more rapid decrease in thickness with cycles of abrasion; which is an effect apparently independent of the corresponding mass changes.

From a brief analysis of these three graphs, it appears that several effects take place simultaneously during the abrasion of the fabrics; a cutting, snagging and frictional action on the fibers leads to breakdown of the surface structure. Some of the fibrous material is lost to the fabric during abrasion and in the brushing action; some of the fibrous substance is ground into the fabric by the pressure of the abradant (the grinding action appears to be more severe in the case of the Taber Abrader); a pressing action takes place simultaneously in the case of the Stoll tests, which leads to a more rapid reduction in thickness than might normally be expected.

4. Relationship between Mass and Permeability Changes

On the assumption that the mass changes are related to the permeability changes, a series of plots of % change in mass vs. % change in permeability was made for the two fabrics as evaluated on the two abrasion machines. As shown in Fig. 4, several straight lines were drawn through the origin, indicating linear relationships between the paired parameters. A summary of the findings is as follows:

Sateen tests (Stoll): This relationship is approximately linear over the entire range of values. The ratio dP/dM* is 14.3. This is consistent with the observations plotted in Figures 1 and 2. The absence of an induction period indicates that mass was not retained to any significant extent by the fabric and that air permeability gain was proportional to mass loss.

Sateen tests (Taber): After a long induction period in which no change in air permeability occurred up to the point that half of the ultimate mass loss of the fabric occurred, air permeability increased proportionally to the mass loss. The ratio dP/dM for this portion of the curve is 9.1. Again these findings are consistent with Figures 1 and 2, which demonstrates significant clogging in the Taber tests of the sateen for an appreciable range of mass losses.

Oxford tests (Stoll): After the slight initial drop in permeability, which then remained relatively constant almost until the end point of the test, the permeability showed a tendency to increase. The slope obtained by connecting the final two points on the curve gives a dP/dM ratio of 8.4. Apparently a small percentage of fiber debris was held by the fabric to produce the initial drop in permeability, but additional debris produced by further abrasion was not retained by the fabric and resulted in progressive decreases in mass

* % change in air permeability divided by % change in mass

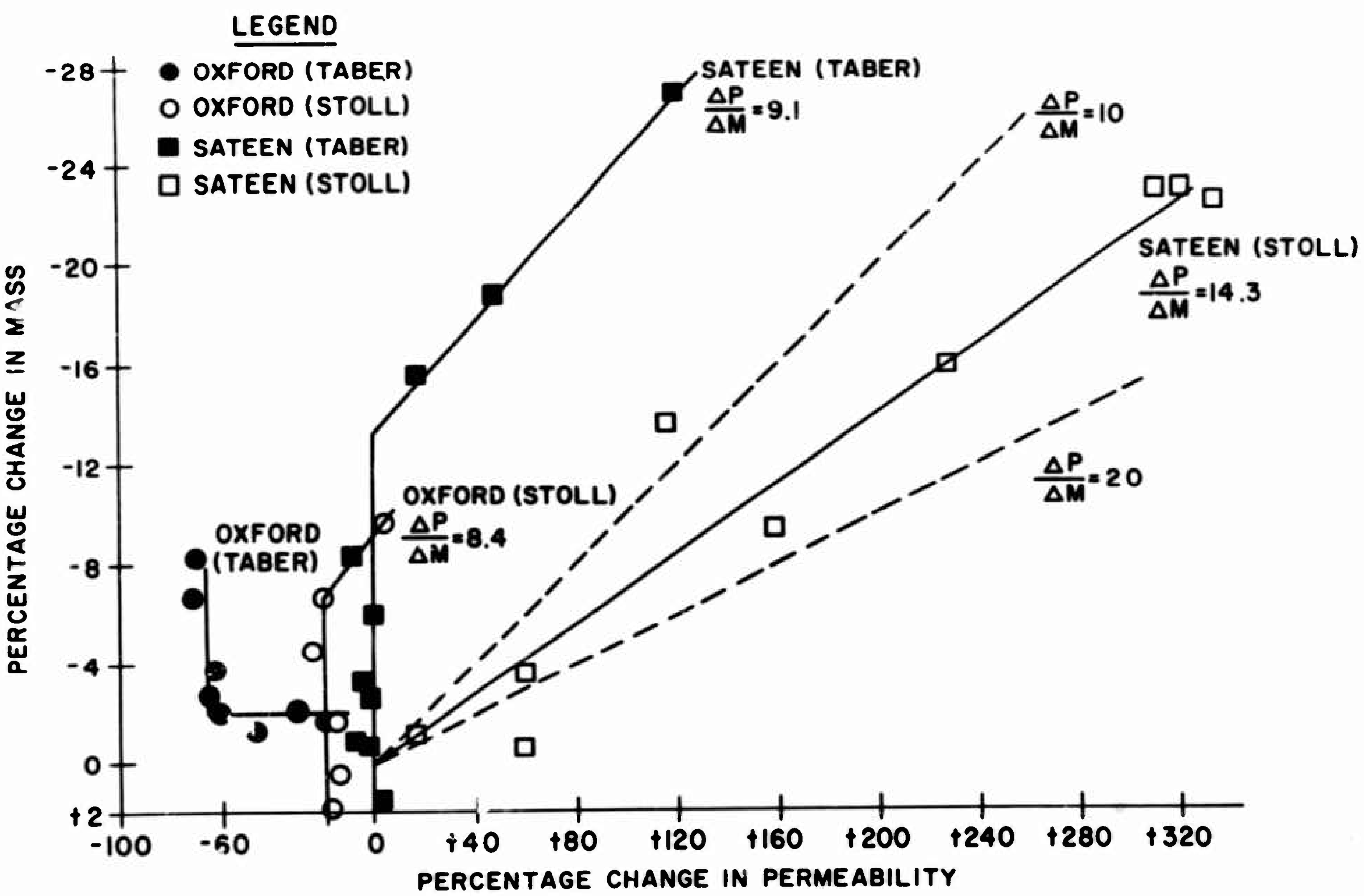

Figure 4. Relationship of Changes in Mass and Permeability During Abrasion of Oxford and Sateen Fabrics

without change in permeability. Toward the end of the test this trend was reversed as the gross structure of the fabric became more disrupted.

Oxford tests (Taber): Whereas in the case of the sateen evaluated on the Taber, it was found that an equilibrium was established during the initial stages of abrasion in which the amount of new fiber debris produced was sufficient to maintain a relative constant air permeability, in the case of the oxford evaluated on the Taber, the total amount of fiber debris produced was picked up by the fabric resulting in a progressive decrease in permeability with no apparent change in mass of the sample. This process continued until a little over 60% decrease in permeability, at which point the permeability remained constant while additional fiber debris produced was not retained by the fabric, as shown by the progressive mass decreases.

The above observations appear to be fairly consistent with each other and with what might be expected from the nature of the instruments involved in the testing. It is interesting to note the relatively uniform changes in properties of abraded textile materials up to the point where gross failure occurs as evidenced by hole formation. For example, in the evaluation of the oxford fabric at its established end point, an area of the fabric with no visible hole had an air permeability of 2.4 $ft^3/min/ft^2$, whereas in an immediately adjacent area, a very small hole increased the permeability to 6.3 $ft^3/min/ft^2$. This increase is quite large when it is realized that the total area occupied by the hole was relatively small compared to the 0.? in^2 of area through which the permeability was measured. In fact, in the case of the oxford fabric evaluated on the Taber, the air permeability decreased on a continuing basis in non-hole areas even up to the selected endpoint, where two holes of significant size were in evidence. Thus, it appears that the change in air permeability during the abrasion of textile fabrics is a rather sensitive measure of the redistribution of mass that occurs.

In general, it appears that the tendency to clogging of a fabric must be a function of the original air permeability or tightness. Closely woven fabrics having low initial air permeability will tend to clog more readily than loosely woven constructions. This is probably a result of the greater possibility of a mechanical binding action in low permeability constructions. Factors other than permeability must have a bearing on the extent of fiber retention by the fabric. Low friction surfaces, existing by virtue of the presence of a lubricating type finish on the fabric or as a result of the inherent frictional characteristics of the fibers, would tend to inhibit the accumulation and retention of fiber debris. The nature of the charge developed in the fibers compared to the fabric would have an influence, also. Fabric thickness, the relative amount of free space within the fibers compared to that between yarns, the types of pores and pore distributions characteristic of different weaves would also have a bearing on fiber retention.

5. Face-to-Back Variations in Permeability

If the concept of clogging is tenable, then it must be assumed that it is a directional phenomenon occurring as a result of fibers being ground into the inter-yarn and possibly the inter-fiber spaces. With respect to the inter-yarn spaces, the mass of fibers must act somewhat as a plug filling up the "holes" in the fabric. The anchorage of these plugs must be such that a stream of air directed toward the broad end of the plug, the end at the abraded face of fabric, would have more difficulty in passing through the fabric than an air stream directed toward the narrow end of the plug, the end at the back of the fabric. Such differences were found to exist. The oxford fabric, abraded on the Taber for 500 cycles, showed face to back increases in permeability from 1.4 to 2.0 $ft^3/min/ft^2$ in one measured location and from 2.2 to 3.4 $ft^3/min/ft^2$ in another.

In another test, a total of 32 face and back measurements were made on 8 specimens of oxford fabric which had been abraded on the Taber Abrader for 50 cycles, 100 cycles, and then in steps of 100 cycles up to 700 cycles. The algebraic differences in Gurley seconds between face and back measurements were computed and the "Chi Square" test was used to determine if a significant difference existed between the number of measurements which were greater as determined on the face (indicative of plugging) or on the back. The raw data and computations are shown in Appendix "I". The number of determinations (24 out of 32) which were greater on the face was significant at the .01 level of probability. The table value of x^2 for the .01 level of probability with 1 degree of freedom is 6.635. The computed value of x^2 was 8.0.

6. Positional Variation in Air Permeability*

In the Taber tests, evaluations of air permeability were made at four positions in the annulus of the abraded path. In positions 1 and 3, the direction of abrasion was perpendicular to the warp. In the case of the oxford, abrasion perpendicular to the warp produced the greatest drop in air permeability (Figure 5). If it is assumed that abrasion perpendicular to the warp is the most severe, it is probable that the greatest amount of fiber debris would be produced in this direction and that there would be a greater tendency for clogging of the pores to occur in those locations where the abradant motion was perpendicular to the warp. In the early stages of abrasion, there did not appear to be an appreciable difference in warp-to-filling direction abrasion as evaluated by permeability differences.

For the sateen in the Taber tests, directional effects did not become evident until the end-point was approached (Figure 6). Assuming, as above, that the abrasion perpendicular to the warp is most severe, then the greatest amount of fiber damage would occur in this direction. Since retention of fiber substance did not take place in the sateen near the end point, greater fiber damage would lead to a more

* See (Appendix D)

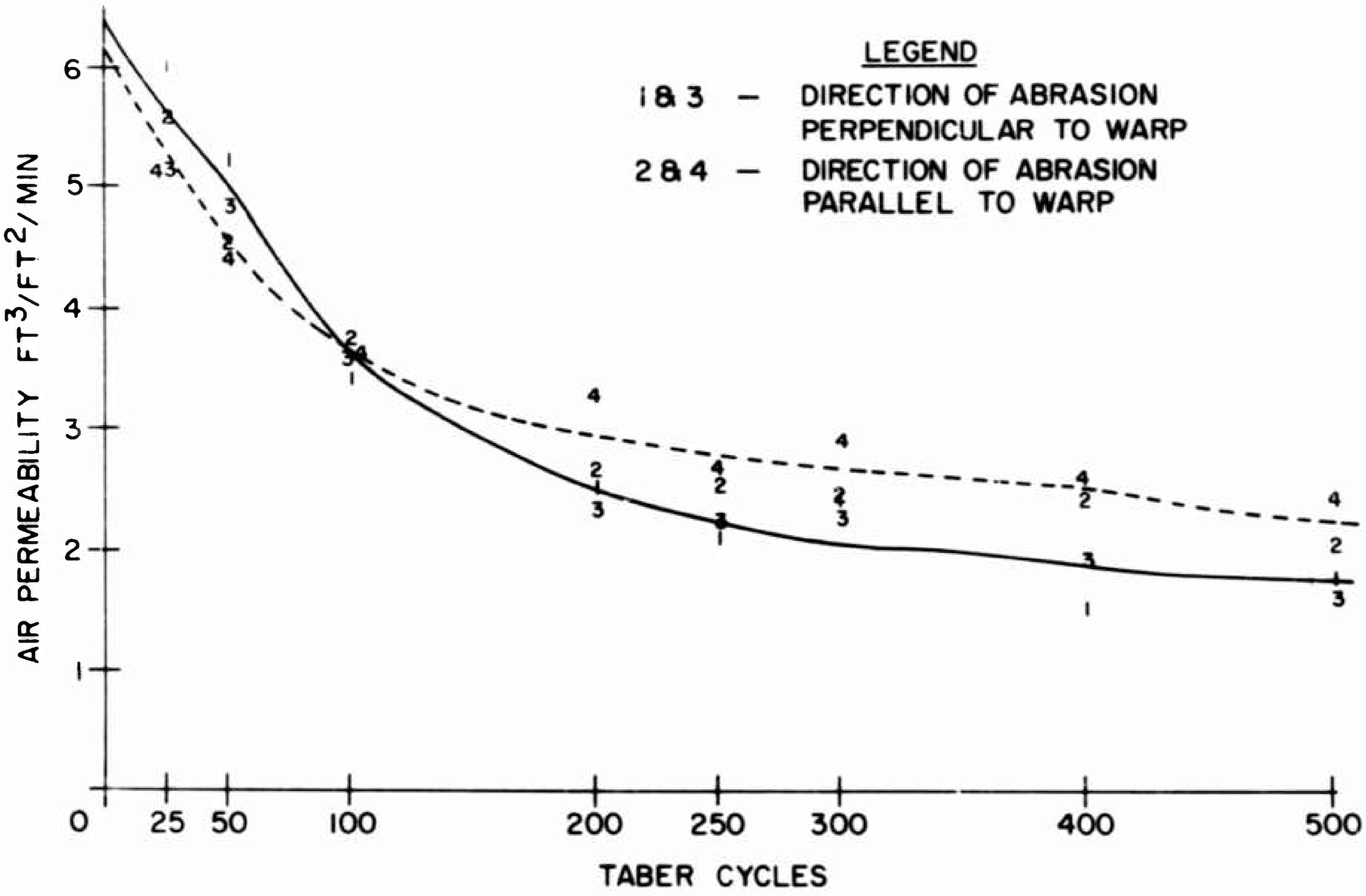

Figure 5. Variation of Air Permeability with Abrasion as a Function of Position of the Measurement on the Abraded Annulus (Oxford on Taber)

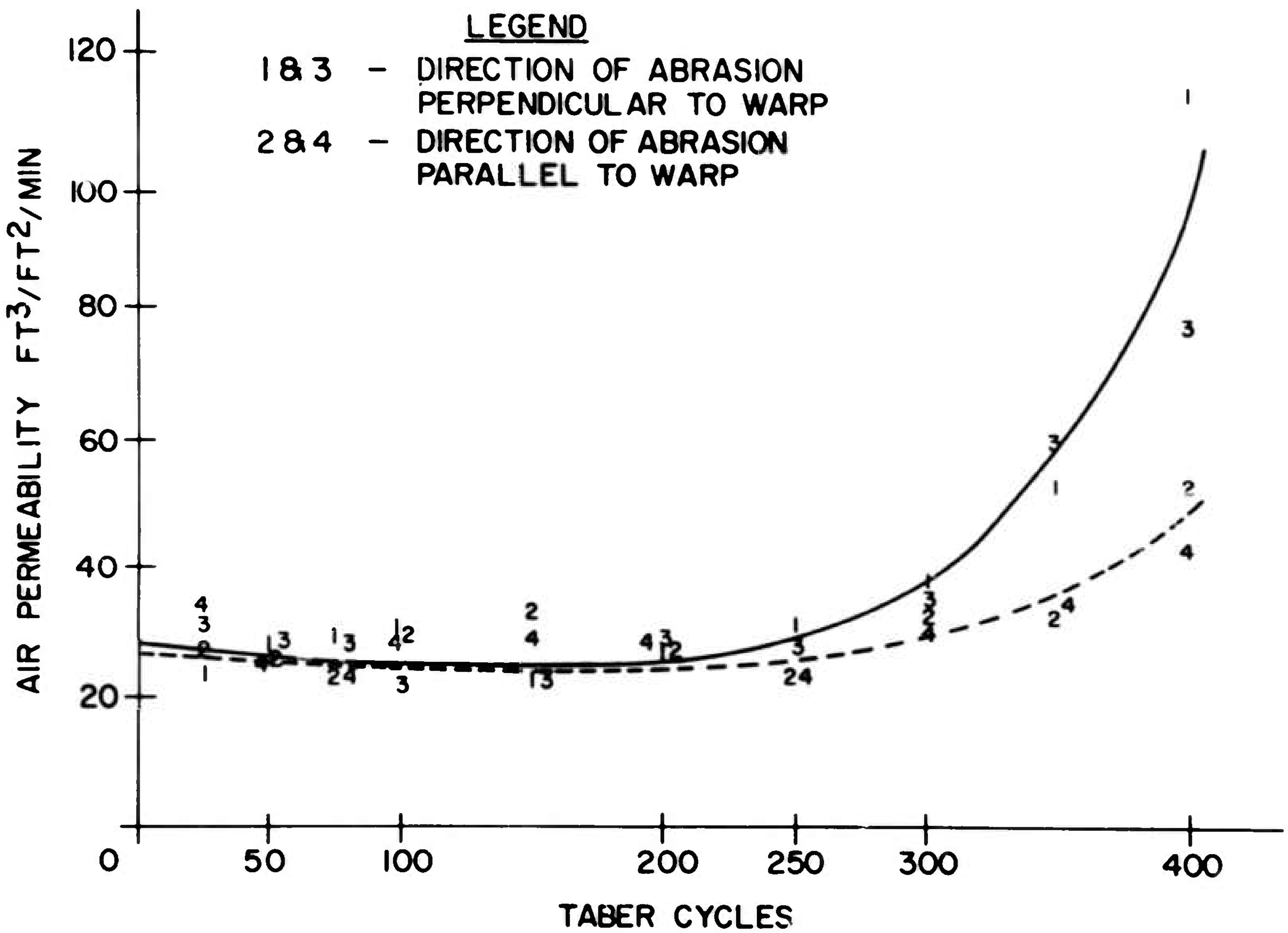

Figure 6. Variation of Air Permeability with Abrasion as a Function of Position of the Measurement on the Abraded Annulus (Sateen on Taber)

rapid denuding of the fabric structure and to more rapid increase in air permeability in those areas suffering greater fiber damage.

An alternative explanation for the difference in behavior of the oxford and the sateen might be in the relative amount of warp and filling yarns exposed to the abradant action during the test. The oxford has a uniform morphology, face to back, but the relative amount of warp yarn is greater than the amount of filling yarn exposed to the abradant. The sateen, which is non-uniform face to back, was evaluated on the back, where the relative amount of filling yarn is greater. In both instances, however, the filling yarns were coarser and there would be a greater tendency for failure to occur in the warp yarns. In actual wear situations, the warp yarns usually constitute the stress-bearing system and failure occurs after abrasion of the warp yarns. In many instances, particularly in the case of sateens worn on the filling flush side, the filling yarns must literally be worn through before the warp yarns are reached.

7. Effect of vacuuming and permeability

The Taber Abrader is equipped with a vacuum attachment having a one-horsepower motor leading to a 0.5 in^2 orifice which is positioned 3/16 inches above the surface of the fabric being abraded. The vacuuming action is continuous as contrasted with brushing, which is intermittent. For the oxford fabric, which had the large reduction in air permeability in wear areas, a spot check showed a difference in air permeability between samples abraded with and without the vacuuming attachment of 16%, where the difference between abraded and unabraded areas differed by more than 100% (based on the lower permeability). Thus, while continuous vacuuming during the course of an abrasion test on the oxford removes some of the fiber debris from the fabric interstices, the amount so removed is small compared to the total amount present.

8. Effect of Laundering* on Permeability

Laundering of the oxford and sateen fabrics that were abraded on the Taber produced a significant increase in air permeability, as shown in Figure 7. In the early stages of abrasion, the differences in air permeability were rather small, but as abrasion progressed the differences became larger. In the case of the oxford, the difference became rather constant at about 2 $ft^3/min/ft^2$ soon after the initiation of abrasion. In the case of the sateen, the difference continued to increase with abrasion, reaching about 20 $ft^3/min/ft^2$ at the end-point. As was the case with the unlaundered fabrics, the laundered oxford decreased in permeability with increasing cycles of abrasion, whereas the sateen increased in permeability with increasing cycles of abrasion. The increase in permeability with laundering must be attributed to removal of fiber debris from the fabric interstices,

* Data and laundering procedure in Appendix E.

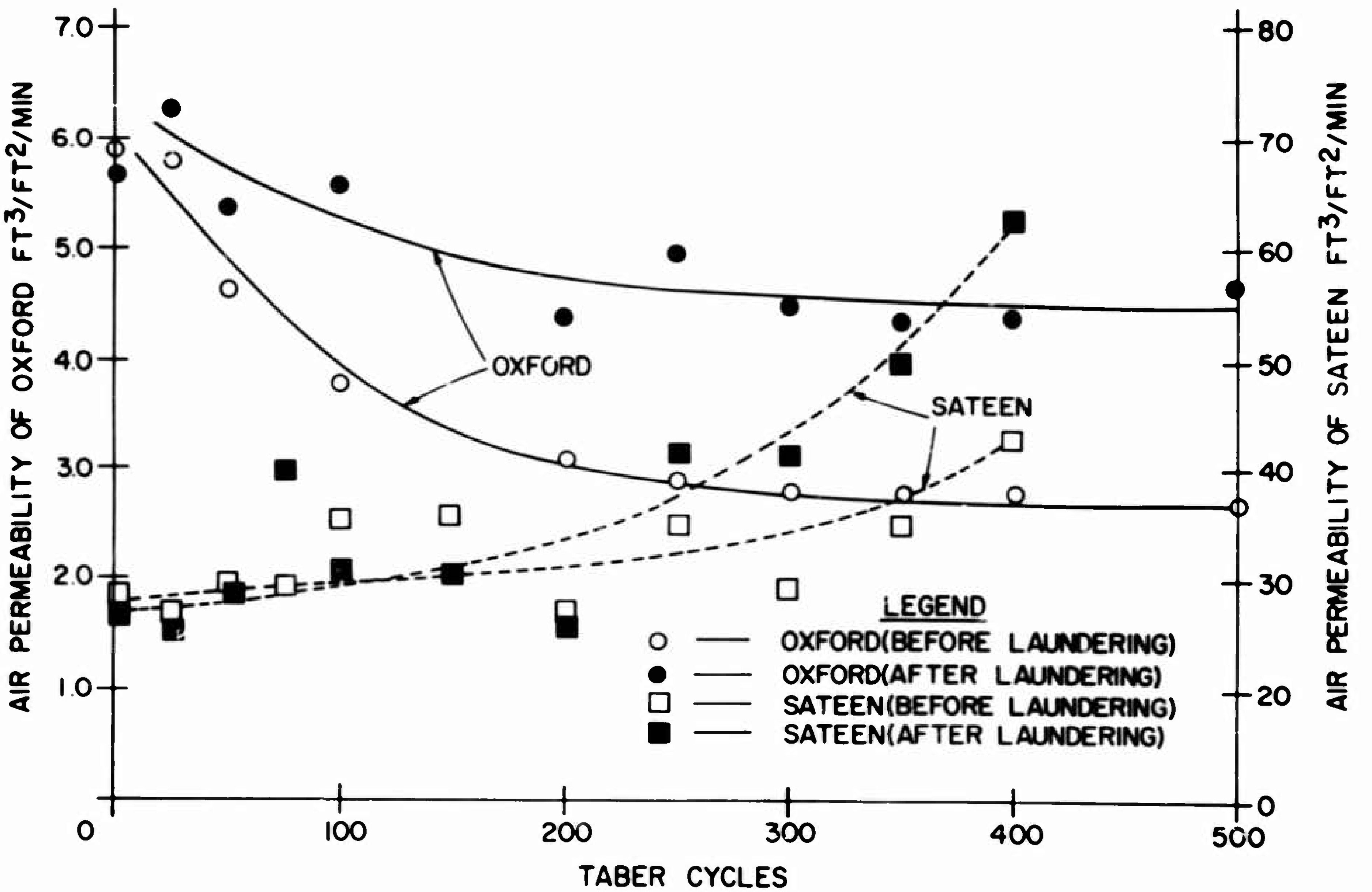

Figure 7. Effect of Laundering on Air Permeability of Oxford and Sateen Fabrics Abraded on Taber Tester

since normally the effect of laundering is reduction in air permeability as a consequence of shrinkage. In the case of the oxford, laundering of the unabraded fabric did produce the expected but slight drop in permeability; but at every stage of abrasion the laundered samples were consistently more permeable than the laundered.

9. Effect of Combined Vacuuming and Laundering

In one test of a different oxford fabric, laundering tests were made on samples which had been abraded on the Taber tester, with and without the vacuum attachment. The results of this test, shown in Figure 8, demonstrated the drop in permeability as a result of abrasion, the increase in permeability following laundering, and finally the higher permeability characteristic of the sample abraded using the vacuum attachment.

Neither vacuuming the sample nor laundering were able to restore the level of air permeability to its original value. Vacuuming had a slight effect both on the unlaundered and laundered fabric.

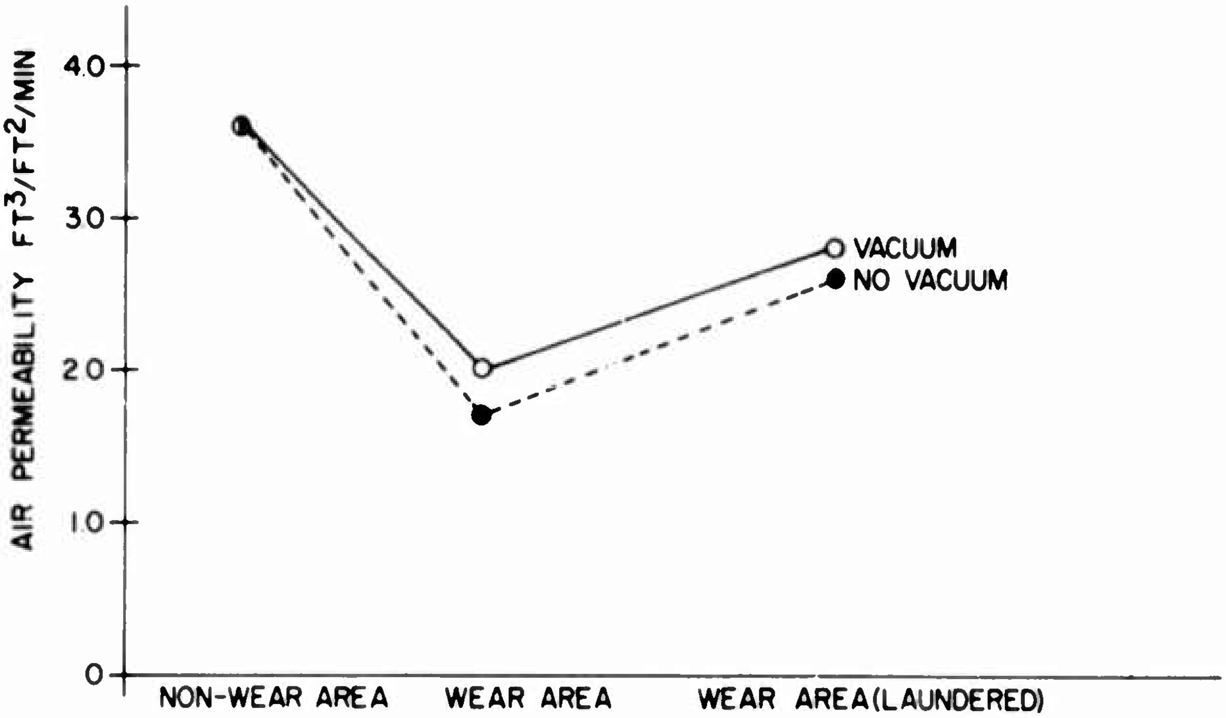

Figure 8. Effect of Laundering on the Air Permeability of Oxford Fabric Abraded on the Taber Tester With and Without the Vacuum Attachment

Laundering had the most significant effect. But the combination of vacuuming and laundering left the fabric more than 20% less permeable than it was originally. The compacting action of the abradant wheels on the fabrics is such that the combined effect of vacuuming and laundering is insufficient to remove all of the fiber debris from the interstices of the oxford fabric.

10. Permeability, Mass, and Thickness Changes in Practical Field Wear Situations*

In order to compare the laboratory findings with observations in a practical field situation, analyses similar to those on the Stoll and Taber testers were made of data obtained by Pope (14) on garments returned from a trouser wear-test conducted on the Cotton Wear Course (15) at Fort Lee, Virginia. The trousers were made from poplins and sateens. The poplins included a 6.0 oz. all-cotton and a 5.5 oz 50/50 cotton/nylon blend. The sateens included an 8.8 oz. carded cotton; a 9.0 oz. wind resistant, water repellent (Quarpel) treated cotton; and an 8.8 oz. 50/50 cotton/nylon blend. One representative pair of each type of poplin trousers was selected from a group which had been subjected to 8 cycles of wear on the Cotton Wear Course. Each cycle of wear consisted of two traversals of the course and one laundering. One representative pair of each type of sateen trousers was selected from a group which had been subjected to 12 cycles of wear on the Cotton Wear Course. Permeability, mass, and thickness measurements were made in a manner identical to those reported for the Stoll and Taber tests in four areas of each garment: 1) a location which had not been directly exposed to wear, but had been subjected to the full complement of launderings; 2) a location which received wear but had no evidence of hole formation; 3) a location in which evidence of hole formation was just beginning; and 4) an area where a very small hole was evident. Measurements were also made of new unlaundered materials of the identical types that were used in the field test. The data obtained are listed in Appendix F and some of the observed relationships are plotted in Figures 9 to 11.

Since the portions of the garments selected for analysis were chosen on the basis of a relative equivalence in wear or hole size, no relationship between mass changes and the relative wear resistance of the fabrics as reported by the field test agency was expected. This was found to be the case. For example, the two fabrics which showed the smallest percent decrease in mass, the poplin cotton and the sateen cotton (Figure 9), were the poorest in their respective tests on the wear course. In addition, since the areas selected were intended to be equivalent in visual appearance of wear, it would be more difficult to find evidence of relationships between mass and permeability changes as were observed in the case of the laboratory tests, which are based on more objective data. Nevertheless, interesting trends were observed. For example, the fabric with the most open construction (sateen cotton -

* Data in Appendix F

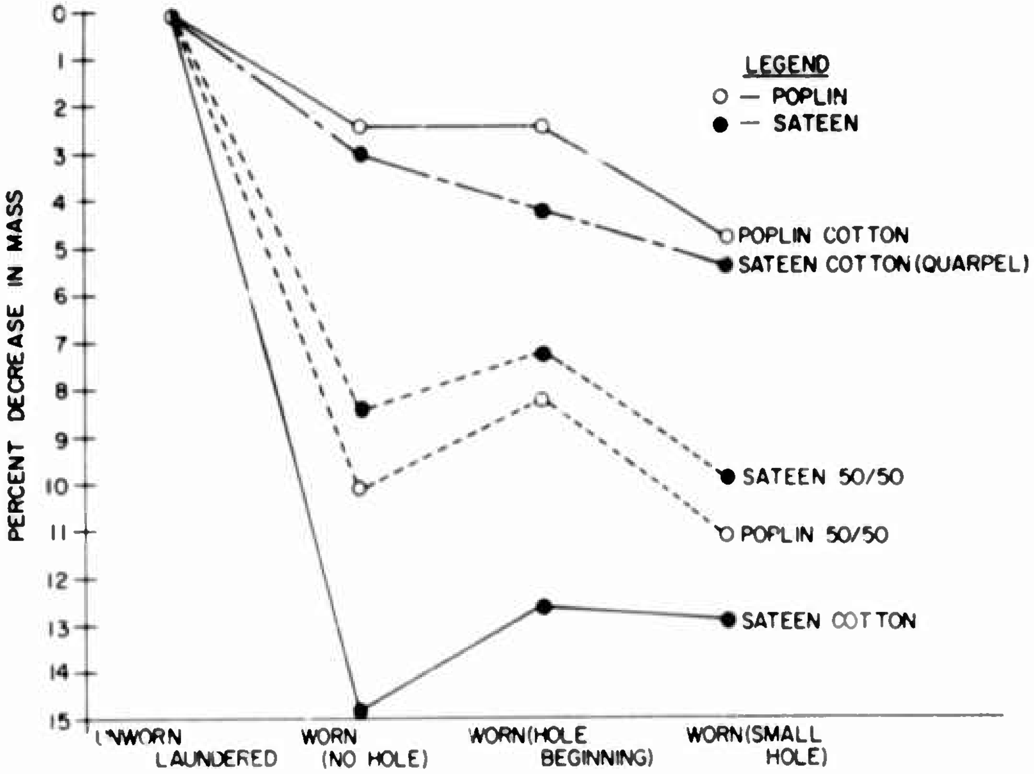

Figure 9. Percent Decrease in Mass for Different Areas in Trousers Worn on Fort Lee Wear Course

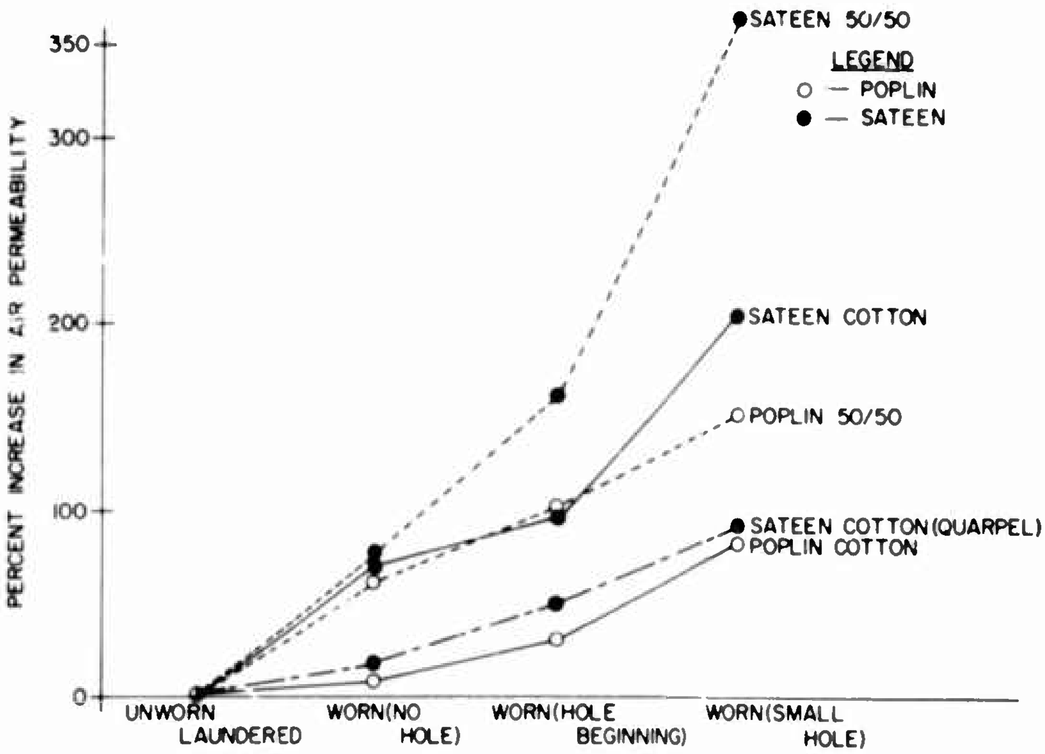

Figure 10. Percent Change in Permeability for Different Areas in Trousers Worn on Fort Lee Wear Course

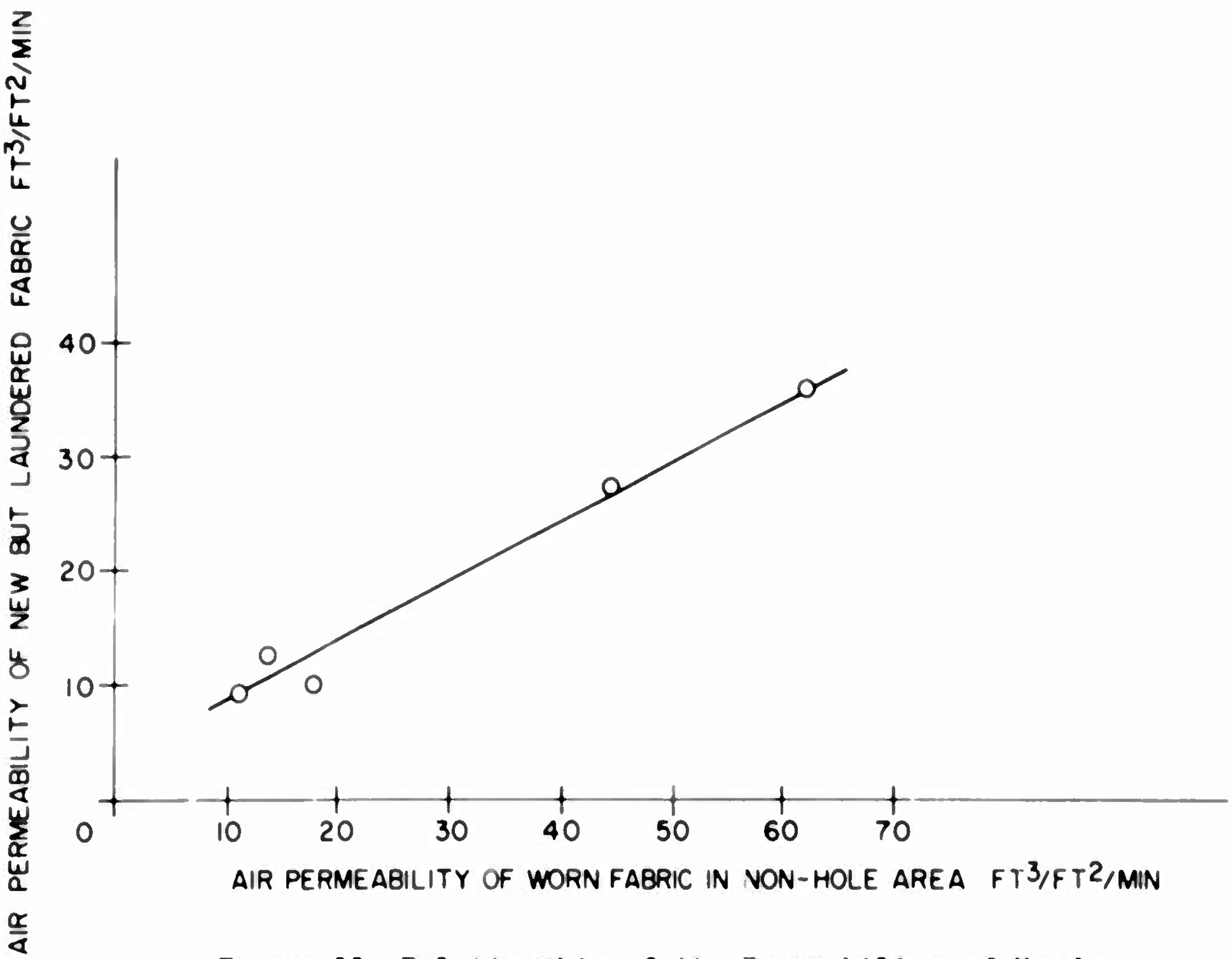

Figure 11. Relationship of Air Permeability of New but Laundered Fabric to Worn Fabric in Non-Hole Area

Table V

Permeability Changes in Fabric from Trousers Worn at Fort Lee

Sample Identification	Percent Change in Permeability (Non-hole Area)
Tight Constructions	
VEE 1110 Poplin Cotton	8.9
VEE 1109 Sateen Cotton (Quarpel)	17.9
VEE 1076 Sateen 50/50	75.5
Loose Constructions	
VEE 1070A Poplin 50/50	60.5
VEE 727 Sateen Cotton	72.2

Figure 9) showed the greatest percent decrease in mass, whereas the two cotton fabrics with the tightest construction (poplin cotton and sateen cotton (Quarpel)) showed the least decrease in mass. The results on the 50/50 cotton/nylon fabrics fell between the above fabrics; although, on the basis of permeability, the sateen (50/50) should have been closer to the tight fabrics and the poplin (50/50) should have been closer to the loose fabrics. However, the trend was in the expected direction, and when the influence of finish interactions arising from potential static effects of the nylon is taken into consideration, the agreement with laboratory findings is fairly good.

In the permeability graph (Figure 10) the two tight cotton fabrics (sateen cotton (Quarpel) and poplin cotton) show the smallest increase in permeability, which is consistent with the smallest decrease in mass observed in Figure 9. However, the 50/50 nylon/cotton fabric departs from a systematic behavior. This can be explained on the basis of variability associated with the method of selection of the area for analysis or, as mentioned in the previous paragraph, on differences arising from fiber composition.

In general, the findings of the field evaluation tend to support some of the deductions made from the laboratory data. But it is obvious that much more work is necessary to identify the factors which influence the manner in which mass is redistributed in fabrics during the field wear process. Figure 11 is a plot of the relationship of the original permeability of the fabric to the permeability observed in a non-hole area after wear. While the relationship appears linear, reference to Table V reveals that two tight fabrics (poplin cotton and sateen cotton (Quarpel)) increased less than 20% in air permeability between the unworn and worn states (non-hole area) whereas the two loose fabrics (poplin 50/50 and cotton sateen) increased more than 60% in air permeability between the unworn and worn states (non-hole area). The fifth fabric, however, (the sateen 50/50) which had a tight construction) increased 75% in permeability, which is anomalous behavior in terms of the laboratory findings.

11. Beta Transmission Measurements

nother technique for obtaining an indication of the mass changes in textile fabrics during abrasion is the Beta Gauge, which measures the transmission or absorption of beta radiation by the mass of the textile structure. The advantage of the Beta Gauge technique is that it is non-destructive and repetitive measurements may be made without influencing any other measurable property of the material. Tests were made on the samples of 8.8 oz. carded sateen abraded on the Taber prior to the specimens being punched for weighing on the analytical balance. The measurements were made using a Tracerlab BGL7C Beta Gauge

with a 350 millicurie krypton 85 source (16). The measurements were reported in arbitrary units of transmission. A plot of the reciprocal of transmission (proportional to mass) versus abrasion cycles is shown in Figure 12 and of the reciprocal of transmission versus measured mass in Figure 13.

The shape of the curve relating the reciprocal of transmission to cycles of abrasion is similar to that observed in Figure 1 for the relationship of change in mass to cycles of abrasion. While one is plotted on a linear basis and the other on a percentage basis, the continuously decreasing slope in each instance indicates that similar characteristics are being measured. As shown in Figure 13, the observed relationship between reciprocal of transmission and mass appears to be fairly linear over the range in mass values encountered in the study of the sateen.

The data on beta radiation transmission are presented as a suggestion for future studies of changes in mass distribution which occur during abrasion. By using the three parameters of permeability, thicknes , and beta transmission, a completely non-destructive series of tests ca be conducted on abraded textiles which will permit a more detailed analysis of the progress of abrasion than could be obtained by using more conventional testing techniques.

12. Consistency of Observations

To provide an indication of the consistency of changes in permeability, an independent experiment was conducted using sateen and oxford fabrics made under the same specification as the original fabrics but obtained from another source. Comparisons were made using the Taber Abrader and involving permeability measurements only. The permeability test was re-evaluated, since the most significant as well as the most unexpected findings in this study were based on permeability. The additional fabrics selected were less permeable than the originals. The sateen had an air permeability of 25.0 $ft^3/min/ft^2$ compared to that of the first fabric of 28.1 $ft^3/min/ft^2$. The second oxford had an air permeability of 3.51 $ft^3/min/ft^2$ compared to the first oxford of 6.9 $ft^3/min/ft^2$.

Whereas, in the first experiment, the sateen showed little change in permeability until near the end point of the test, in the second experiment, using the somewhat less permeable sateen fabric, the clogging tendency was more evident by a drop in permeability which continued at a decreasing rate to practically the end point of the test.

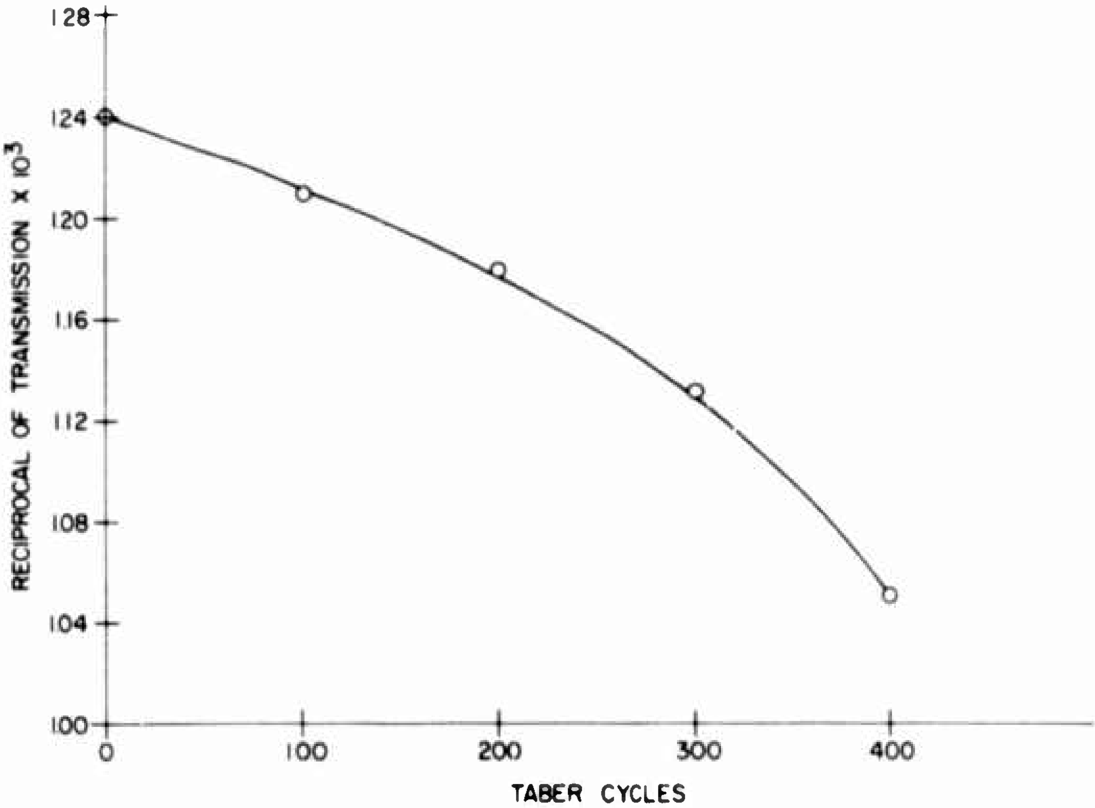

Figure 12. Change of Reciprocal of Transmission of Sateen Fabric during Abrasion on Taber Tester

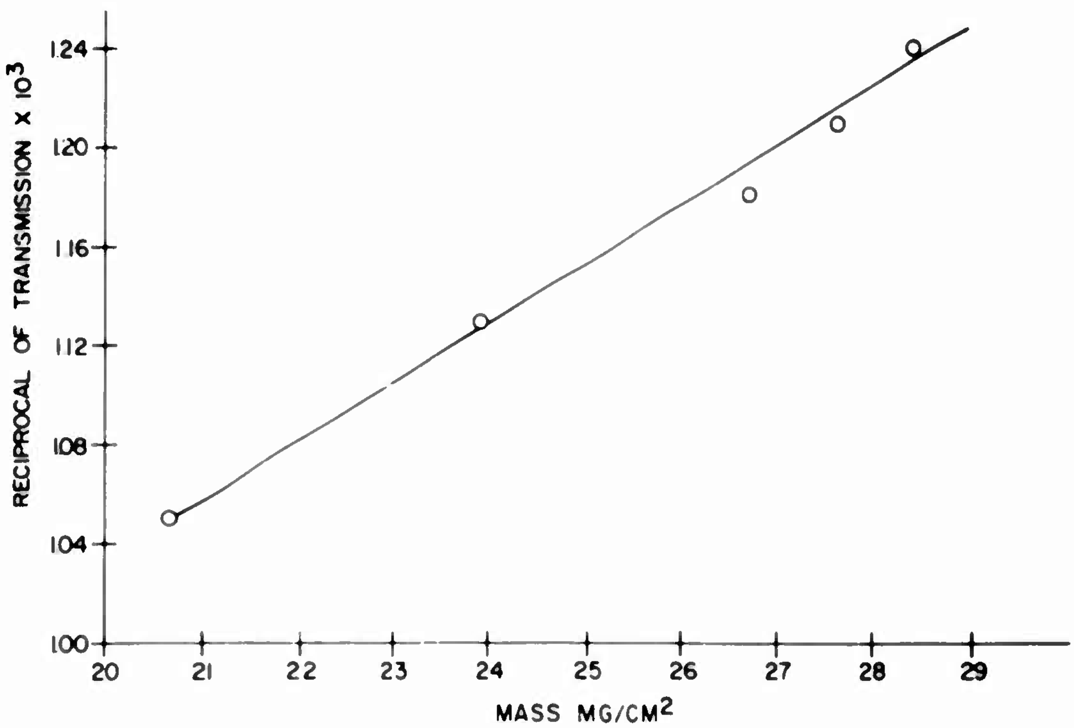

Figure 13. Relationship of Mass to Reciprocal of Transmission (Sateen Abraded on Taber)

As pointed out in the discussion of the first sateen fabric (that maintenance of a constant permeability is an indication of clogging, otherwise increase in permeability is to be anticipated) the decrease in permeability of the tighter sateen construction indicates that clogging takes place at a more rapid rate. Whether this phenomenon is completely associated with the somewhat tighter construction of the second sateen would be of interest to determine.

In the second oxford fabric, the curve relating percentage change in permeability to percentage of cycles to end point practically parallels that of the first oxford fabric. Thus, in both instances, the decreasing air permeability from the initiation of the test until leveling off occurs near the end point of the test indicates that clogging is a significant abrasion mechanism in oxford fabrics. The similarity in shape of the two curves for the oxford fabrics, when coupled with the difference in original permeability and the actual displacement of the two curves in the percentage change plots, suggested the desirability of representing the absolute rather than the relative data by equations to permit a more detailed analysis of the mechanisms of clogging in terms of the constants of the equations. This analysis is presented below.

13. Representation of the Oxford Data by Equations

The data for the two oxford tests are given in Table VI. For increased consistency, data points were selected at every 100 cycles of abrasion, except a 50-cycle point for each fabric was also selected since the curve relating air permeability to abrasion cycles changed most rapidly during the initial period of abrasion.

Table VI

Permeability Data for the Two Oxford Fabrics

Cycles	Oxford #1	Oxford #2
0	6.9	3.51*
50	4.8	2.96
100	3.6	2.63
200	2.7	2.17
300	2.5	2.24
400	2.1	1.74
500	1.9	1.58
600		1.52
700		1.51

* Three significant figures were retained during the analysis of the second oxford.

Figure 14 shows plots of the two sets of data on rectilinear coordinates. Smooth curves could be drawn through the two sets of points, with the exception of the 300-cycle point for the second oxford. Analyses of the curves were made with and without this one point on the

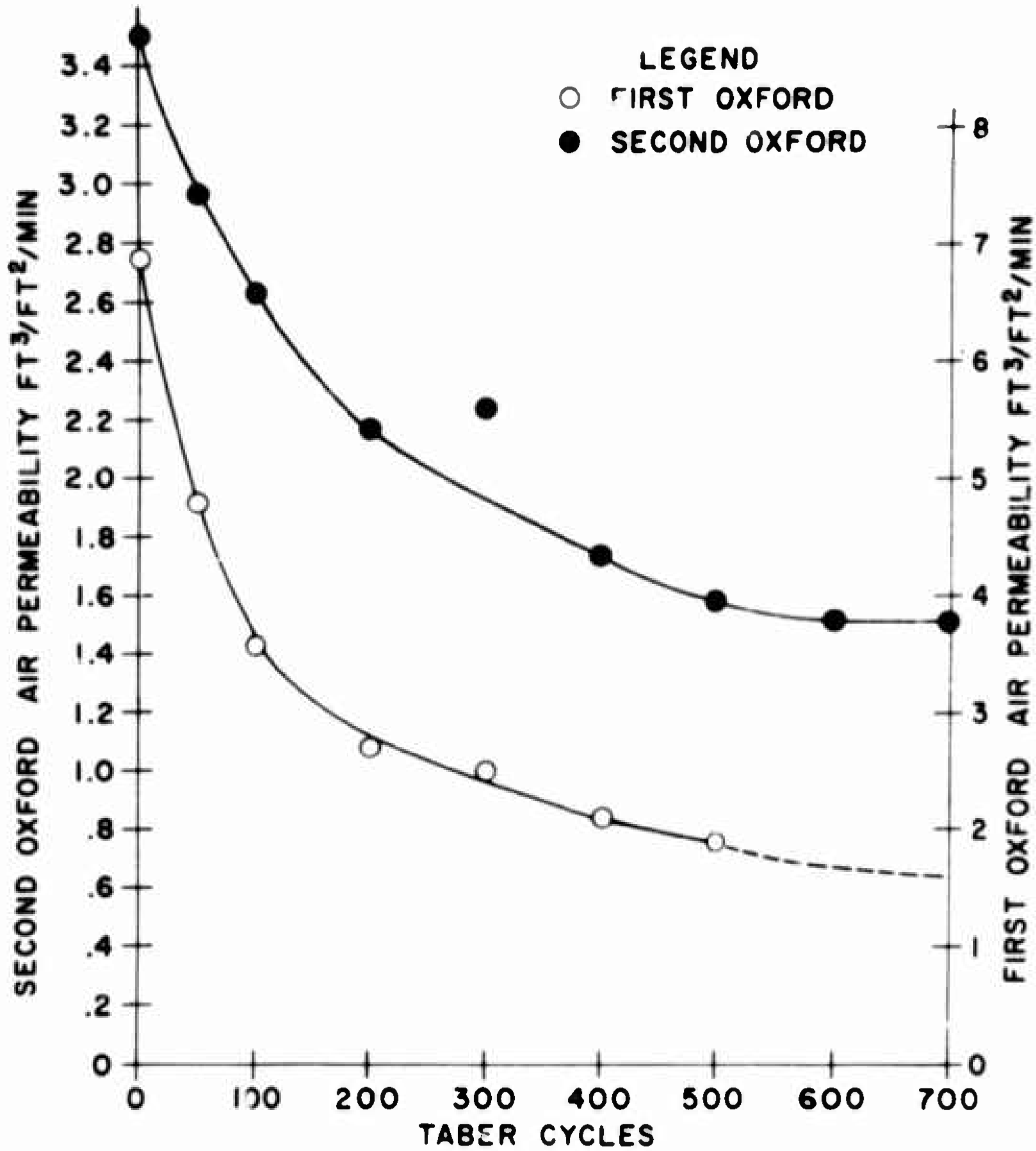

Figure 14. Variation of Air Permeability with Abrasion of Two Oxford Fabrics (Taber Abrasion)

assumption that it may have been a testing artifact. Both curves appeared to be of an exponential form. The curve for the first trial has an intercept on the air permeability axis of 6.9 $ft^3/min/ft^2$ and an asymptote parallel to the cycles of abrasion axis of approximately 1.6 $ft^3/min/ft^2$. The curve for the second trial has an intercept on the air permeability axis of 3.51 $ft^3/min/ft^2$ and a corresponding asymptote of approximately 1.5 $ft^3/min/ft^2$. The permeability for the first fabric dropped much more rapidly for equivalent cycles of abrasion. On the assumption that the relationships could be expressed as exponentials of the form $A = ae^{bC}$ (where a and b are the conventional constants of the exponential equations and A and C are air permeability and cycles of abrasion respectively), plots were drawn of log A versus C in the hope of obtaining straight lines, since, for the given exponential, $\log A = \log a + \frac{b}{2.3} C$ where log a is the

intercept on the log air permeability axis and the slope of the line is $\frac{b}{2.3}$. For both sets of data, the log A versus C plots appeared to be curvilinear, although in the case of the first oxford fabric several of the points fell along a straight line, which could provide a basis for initiating the computations to obtain an equation. A second trial plot was made of the log of the quantity (A - asymptote) versus C. For the first oxford material, this was log (A - 1.6) and, for the second oxford, log (A - 1.5)*. These plots, shown in Figure 15, gave distinctly linear portions.

In the case of the first oxford, the linear portion consisted of three points corresponding to the lowest values of cycles of abrasion, which are the most critical in determining the equation since the differences among air permeability values become less as the cycles of abrasion increase. For the second oxford, the linear portion consisted of five points. For the first oxford, the balance of the plotted points were located in a region of the graph below the projected straight line. This suggested that a more exact formulation of the equation would involve, in the former case, an exponential <u>plus</u> a residual term or value, while in the latter case an exponential <u>minus</u> a residual term or value would be appropriate. However, the values of the residuals were insignificant in their influence on the basic exponential because of the leveling off of air permeability at high abrasion cycles. The solution of the residuals and the exponentials as shown in Appendix J led to the following equations:

$$\text{First oxford } (A) = 5.30e^{.00983C} + 1.60$$

$$\text{Second oxford } (A) = 1.94e^{-.00524C} + 1.45$$

An indication of the closeness of match of these equations to the actual data is demonstrated in Table VII, which shows the values of air permeability obtained experimentally with those calculated theoretically. In the case of the first oxford, the average deviation of the experimental values from theory was .11 $ft^3/min/ft^2$ whereas, for the second oxford, it was only .03 $ft^3/min/ft^2$. The interpretation of the parameters, of the equations is as follows:

1. When the value of C is zero (i.e., the unabraded fabric), the air permeability is the sum of the coefficient of "e" and the constant term of the equation, e.g., 1.94 + 1.45 = 3.39, which is the air permeability of the original unabraded fabric.

2. When the value of C becomes very large, the value of e^{-bC} drops toward zero and the exponential term becomes insignificant in comparison to the constant term of the equation. The air permeability then becomes equal to the constant term, which is the asymptote noted above. The asymptote is significant in terms of the fact that the air permeability of the fabric does not decrease below this value as a result of

* Data for these and subsequent computations are given in Appendix J.

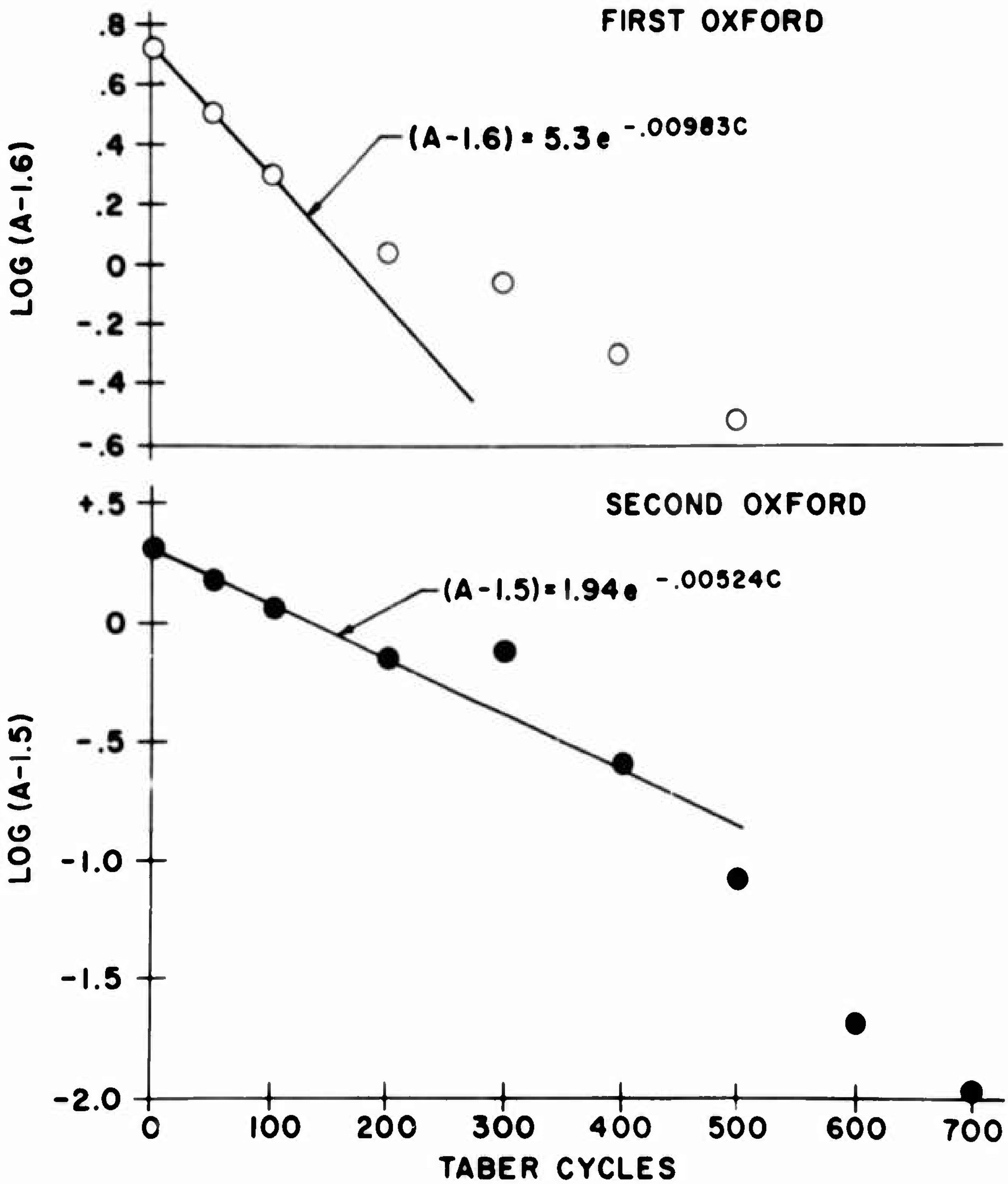

Figure 15. Plot of Log (A-1.6) for First Oxford and Log (A-1.5) for Second Oxford versus Cycles Showing Linear Portions of Curve Used to Compute Exponentials

Table VII

Comparison of Experimental Values of Air Permeability with Values Computed from Exponential Equations

First Oxford			Second Oxford		
	Air Permeability (A)			Air Permeability (A)	
Cycles (C)	Experimental	From Equation	Cycles (C)	Experimental	From Equation
0	6.9	6.9	0	3.51	3.39
50	4.8	4.8	50	2.96	2.94
100	3.6	3.7	100	2.63	2.59
200	2.7	2.3	200	2.17	2.14
300	2.5	2.1	400	1.74	1.69
400	2.1	2.0	500	1.58	1.59
500	1.9	1.9	600	1.52	1.53
			700	1.51	1.50

Average Deviation = .11 $ft^3/min/ft^2$ Average Deviation = .03 $ft^3/min/ft^2$

clogging. In other words, the fiber debris which accumulates clogs the pores of the fabric up to a certain point, beyond which additional abrasion does not lead to any additional clogging. For the first oxford, this value was 1.60 $ft^3/min/ft^2$, and for the second oxford 1.45 $ft^3/min/ft^2$. The fact that these values are so close despite the fact that the original fabrics differed in air permeability indicates that it is possible for somewhat more clogging to take place in the more permeable fabrics, but that once a certain limit of clogging is reached no further fiber debris can be retained by the fabric, or if it is retained it does not lead to any further decrease in permeability. Of course, at this point in abrasion, gross destruction of the fabric structure begins to set in with the attendant marked rise in air permeability due to hole formation.

3. The "b" constants in the equations, namely -.00524 and -.00983, provide an indication of the rates at which the air permeability of the fabrics are dropping as abrasion continues. Since the "b" constant in the equation for the first oxford is just about twice the value of the "b" constant of the second oxford, we must conclude that at least in the initial regions of the curves, air permeability is dropping at about twice the rate in the first oxford for equivalent abrasion. The value of the

exponential at e^{-1} is 1/e th its initial value. The value of abrasion cycles which will reduce the air permeability to 1/e th its initial value may be considered as analagous to a "time constant" which characterizes the change of permeability with respect to abrasion.

For the first oxford when $.00983C = 1$, the exponent of "e" will be -1 and $C = 102$ cycles. For the second oxford when $.00524C = 1$, the exponent of "e" will be -1 and $C = 191$ cycles. Since 1/e th is approximately 1/3, the air permeability of the first fabric less the asymptote will drop to 1/3 of its unabraded value at approximately 102 cycles of abrasion, whereas the second fabric will drop to this point at approximately 191 cycles. It should be noted that the constant term of the equation must be taken into consideration in making computations of this type. Table VIII shows the correspondence between the air permeabilities computed from the equation at the number of cycles corresponding to the "time constants" and the experimental values at about these same values:

Table VIII

Observed versus Computed Air Permeabilities

Oxford Fabric	Initial Air Perm. ($ft^3/min/ft^2$)	Cycles Corresponding to "Time Constant" (c)	Observed Air Perm. at C	Computed Air Perm. at C
First	6.9	102	3.60	3.55
Second	3.51	191	2.17	2.21

The above analysis for the second oxford was made with the datum point for 300 cycles omitted since it was considered an artifact. The general conclusions obtained are not altered if this datum point is included. The two equations obtained, with and without the datum point are compared below:

$$\text{Without Point } A = 1.95e^{-.00524C} + 1.45$$

$$\text{With Point } A = 1.86e^{-.00444C} + 1.50$$

14. Analysis of Percentage Change Data

While the permeability data for the oxford fabrics were subjected to detailed analysis as shown in the previous section, the nature of the percentage change data obtained on mass, thickness, and permeability was such that detailed analysis was not considered necessary. However, the trends of these plots, as shown in Figures 1 to 3 inclusive, were indicative of fairly strong relationships between each of the variables with cycles of abrasion. Since a linear regression program was available for a GE 225 computer, correlation coefficients "r" were computed for the

relationships of Figures 1 to 3. The "r" values obtained are shown in Table IX. The correlation coefficients are significant at the 95% confidence level. The "r" values are all surprisingly high considering the obvious non-linearity of the data. For both fabrics on both abraders, mass, permeability, and thickness changes are highly correlated with abrasion cycles in 3 out of 4 instances for each parameter. It should be noted that the correlations for mass are all negative, which indicates that mass decreased as cycles of abrasion increased. Only in the case of the oxford abraded on the Taber is less than 50% of the variability explained by the relationship between mass and abrasion. For permeability changes, the sateens showed positive correlations, indicating an increase in permeability with abrasion; whereas the oxfords showed negative correlations, indicating decreases in permeability with abrasion. In the case of oxford fabric abraded on the Stoll, elimination of a specimen which showed distinct hole formation (which would raise the permeability to an abnormally high level) improved the correlation both in magnitude and sign. The thickness correlations were all negative, as would be expected, and were all high except one instance, again where less than 50% of the variability could be explained by the relationship of the variables.

Table IX

Correlation Coefficients of
Cycles to End Point (%) versus Change in Parameter Listed (%)

		Oxford	Sateen
Mass			
Stoll		-.79	-.87
Taber		-.69	-.87
Permeability			
Stoll	.43	-.71*	.85
Taber		-.78	.67
Thickness			
Stoll		-.60	-.85
Taber		-.72	-.85

* This correlation coefficient was obtained when the value of permeability for the specimen which showed distinct hole formation was omitted.

The excellent correlation values obtained emphasize the usefulness of the selected parameters as predictors of the mechanics of abrasion. It is probable that in part the variability not explained by these linear correlation coefficients could be explained on the exponential basis used in the special study of the permeability changes of the oxfords. Any subsequent work in this field should consider deriving linear correlation coefficients based upon log of the parameters versus abrasion cycles.

Table X provides correlation coefficients computed during the same computer program for the laundering and Beta transmission studies. As may be noted, the values of "r" obtained are high and the values of "r^2" indicate that a high percentage of the variability may be explained by the relationship of the variables.

Table X

Correlation Coefficients of Laundering and Beta Transmission

	r	r^2
Unlaundered vs. Laundered	.80	.64
Reciprocal of Transmission vs. Taber Cycles (sateen)	-.78	.61
Reciprocal of Transmission vs. Mass (Taber-Sateen)	.80	.64

CONCLUSIONS

1. The rate of mass loss from textile fabrics during abrasion is a complex function of the inherent abrasion resistance of the fabric, of the geometry of the structure, and possibly of fiber and finish effects as well as of machine interactions.

2. Changes in permeability which occur during abrasion demonstrate that the rate of mass loss is significantly influenced by the extent to which the fabric retains fiber debris during the course of abrasion. Permeability may increase from the inception of abrasion to the end point; it may remain constant during an induction period and then increase with further abrasion; or it may even decrease throughout the test until hole

formation is initiated by the abrasive action. The major factor influencing the permeability changes is the geometry of the fabric. Other factors may include fiber, finish, and machine interactions.

3. Thickness decreases during the abrasion of fabrics. The rate of decrease in thickness appears to be a function of machine type, although factors such as fabric structure and fiber content may have an influence also.

4. Analysis of garments from field-wear tests confirms some of the observations made in the laboratory on factors which influence mass and permeability change.

5. A significant portion of the fiber debris accumulates in the pore spaces in abraded fabrics as a plug. Face-to-back differences in air permeability demonstrate the existence of such a plugging phenomenon.

6. Vacuuming and laundering textile fabrics after abrasion tend to remove some of the accumulated fiber debris, but the amount so removed is not significant in terms of the total amount present.

7. Studies of positional variations in permeability indicate that the greatest changes in air permeability occur when the direction of abrasion is perpendicular to the warp. In the sateen fabric this corresponds to an increase in permeability; in the case of the oxford to a decrease.

8. The decrease in permeability of oxford fabrics with abrasion can be represented by simple exponential functions, the constants of which may be explained in terms of the mechanism of abrasive action.

9. For oxford fabrics, there appears to be a limit to the amount of clogging which may occur. This limit is independent of the original permeability of the fabric.

10. The utilization of the semi-micro techniques developed for characterizing the permeability, thickness, and mass of abraded fabrics provide useful analytical procedures for studying changes in properties which occur in relatively small areas of fabric structure.

RECOMMENDATIONS FOR FUTURE WORK

The present investigation has established that the rates of change of some well established variables used in determining end points in abrasion may be used to characterize the abrasion process in terms of mechanisms which influence the course of abrasion. The present study was limited as to the number of fabrics evaluated and as a result it was possible to reach only the most general conclusions regarding mechanisms. Future work should be concerned, therefore, with evaluating a broader range of fabrics. This could be accomplished in several steps, as follows:

1. Evaluation of cotton fabrics in the 6.0 to 9.0 oz/yd^2 range. A useful series of fabrics to employ this study might be the ITT fabrics (available at the Army Natick Laboratories) in which controlled variables in cover and weave are available. Other samples might include a conventional series of commercial cotton fabrics - say in the three basic weave types with 2 or 3 step variations in fabric cover for each weave.

2. Comparison of fabrics made from different fibers. This might be somewhat more difficult to do if it is desired to keep other factors, such as fabric cover, constant. By selecting 2 or 3 steps of fabric cover for each of three or four fiber types, it might be possible to segregate fiber from cover effects.

3. Steps 1 and 2 above are suggested on the assumption that cover is a critical factor governing the clogging mechanism. Some study should be made of factors, such as finish, which may influence the pick-up and retention of fiber debris. For example, comparisons could be made of identical fabric structures, with and without a water repellent or resin crease-resistant finish.

4. While the degree of fiber retention or rejection, as measured by the air permeability test, provides an understanding of some of the mechanics of the abrasion process, its greatest utility should come from determining what happens in a real service wear situation. The field comparisons made in the current study were not completely valid since visual assessments of the extent of wear in a garment were made, after the fact, by selecting areas of differing wear in a garment which had been worn for a fixed length of time. Future studies of this type should involve preselecting, for analysis, several small areas in garments. The garments could then be subjected to a controlled wear situation which will allow periodic non-destructive measurement of the parameters considered in this study as a function of time.

5. The significant exponential relationships derived for the oxford fabrics suggest that the clogging mechanism could be explained on the basis of a filtering action governed by the particle size of the fiber debris, the pore space in the fabric, and the compressive force of the abradant. Micrometry of the fiber debris in conjunction with pore space analysis could provide useful parameters to determine constants of the equations developed for filtering systems.

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APPENDIX A

Construction Parameters of Experimental Fabrics

	Cloth, Cotton Oxford Type VI	Cloth, Cotton Sateen, Carded
Weight	5.5 oz/yd^2	8.4 oz/yd^2
Texture		
Warp	196	89
Filling	86	55
Yarn Number		
Warp	72/2	14/1
Filling	36/1	10/1
Cover Factor (Texture/ $\sqrt{N}$)		
Warp	32.7	23.8
Filling	14.3	17.4
Cover Factor Sum	47.0	41.2
Maximum Filling Cover Factor*	14.1	24.5
Measured Filling Cover Factor	14.3	17.4
% of Maximum Tightness	100%	71%

* From Textile Series Report No. 128

APPENDIX B

Derivation of Conversion Factors for Permeability and Mass

$$\text{Mass (mg/cm}^2) = \frac{\text{Mass (mg) of 3/8" diameter specimen}}{.711}$$

Conversion to Decimal: 3/8 = .375"

Conversion to Area (in^2): $A = \frac{\pi d^2}{4} = \frac{3.14 \times .375^2}{4} = .111\ in^2$

Conversion to cm^2: $.111\ in^2 \times 2.54^2 = .711\ cm^2$

$\therefore$ 3/8" diameter specimen has area of .711 cm^2

$$\frac{\text{Mass of 1 cm}^2}{\text{Mass of .711 cm}^2} = \frac{1}{.711}$$

$$\text{Mass (mg/cm}^2) = \frac{\text{Mass (mg) of .711 cm}^2\text{ (3/8" diameter) specimen}}{.711}$$

$$\text{Air Permeability* (ft}^3\text{/min/ft}^2) = \frac{917.7}{\text{seconds for 300 cc (Gurley)}}$$

$$ft^3/min/ft^2 = \frac{300 \times 144 \times 60 \times 4078}{G \times 28317 \times 0.1 \times 4065}$$

300 = number of cm^3 of air passing through the instrument in "G" seconds

28317 = number of cm^3 in a ft^3

144 = number of in^2 in a ft^2

0.1 = area of cloth in Gurley (in^2)

$\frac{4078}{4065}$ = correction to reduce air volume to standard pressure conditions

* at 1.26" water pressure differential (based on weight and dimensions of Gurley cylinder - 5 oz, 2 15/16"diam)

APPENDIX C

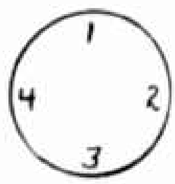
Table of Computations Giving Percentage of Cycles to End-Point for Various Levels of Abrasion

Observed Cycles	Cycles at End-Point			
	400 Cycles	500 Cycles	600 Cycles	2400 Cycles
0	0	0	0	0
25	6.25	5	4.17	1.04
50	12.5	10	8.3	2.08
75	18.75	15	12.5	3.13
100	25	20	16.7	4.17
150	37.5	30	25	6.25
200	50	40	33.3	8.33
250	62.5	50	41.7	10.4
300	75	60	50	12.5
350	87.5	70	58.3	14.6
400	100%	80	66.7	16.7
500		100%	83.3	20.8
600			100%	25.0
900				37.5
1200				50
1500				62.5
1800				75
2100				87.5
2400				100%

APPENDIX D

Positional Variations in Permeability of Oxford Abraded on Taber

Cycles	Air Permeability ($ft^3/min/ft^2$) Direction of Abrasion Perpendicular to Warp		Direction of Abrasion Parallel to Warp	
	Pos. 1	Pos. 3	Pos. 2	Pos. 4
25	6.0	5.1	5.6	5.1
50	5.2	4.9	4.6	4.5
100	3.4	3.6	3.7	3.6
200	2.6	2.4	2.7	3.2
250	2.1	2.3	2.6	2.7
300	2.4	2.3	2.5	2.9
400	1.6	1.9	2.5	2.6
500	1.7	1.6	2.1	2.4



APPENDIX D (cont'd)

Positional Variations in Permeability of Sateen Abraded on Taber

Air Permeability ($ft^3/min/ft^2$)

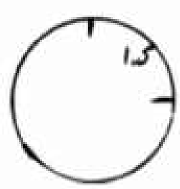
Cycles	Direction of Abrasion Perpendicular to Warp		Direction of Abrasion Parallel to Warp	
	Pos. 1	Pos. 3	Pos. 2	Pos. 4
25	23.9	31.0	27.4	33.8
50	28.0	27.9	27.0	25.5
75	29.6	28.3	23.5	22.4
100	31.1	21.9	30.6	27.5
150	23.6	23.3	33.0	28.3
200	26.9	28.6	27.6	28.1
250	30.0	27.9	22.5	23.5
300	37.5	34.8	31.9	28.9
350	52.7	59.7	31.7	33.1
400	114.1	76.5	52.4	42.0

APPENDIX E

Effect of Laundering on Permeability of Oxford Fabric Abraded on Taber in Position "1.5"*

Cycles of Abrasion	Air Permeability ($ft^3/min/ft^2$)	
	Before Laundering	After Laundering
0	5.9**	5.7**
25	5.8	6.3
50	4.6	5.4
100	3.8	5.6
200	3.1	4.4
250	2.9	5.0
300	2.8	4.5
350	2.8	4.4
400	2.8	4.4
500	2.7	4.7

* Position 1.5 on Taber samples:



** Average of 9 Measurements

APPENDIX F

Mass Measurements of Fabric From trousers Worn at Ft. Lee

Sample Identification	Parameter	Unworn Laundered	Worn No Hole	Worn Hole Beginning	Worn Hole
Poplin Cotton VEE 1110	Mass (gm/cm^2)	0208	.0203	.0203	.0198
	Change (%)*		-2.4	-2.4	-4.8
Poplin 50/50 1070A	Mass (gm/cm^2)	.0207	.0186	.0190	.0184
	change (%)		-10.1	-8.2	-11.1
Sateen Cotton 727	Mass (gm/cm^2)	.0318	.0271	.0278	.0277
	change (%)		-14.8	-12.6	-12.9
Sateen 50/50 1076	Mass (gm/cm^2)	.0333	.0305	.0309	.0300
	change (%)		-8.4	-7.2	-9.9
Sateen Cotton (Quarpel) 1109	Mass (gm/cm^2)	.0332	.0322	.0318	.0314
	change (%)		-3.0	-4.2	-5.4

* Percentage change based on unworn laundered control.

APPENDIX F (cont'd)

Permeability Measurements of Fabric from Trousers Worn at Ft. Lee

Sample Identification	Parameter	Unworn Laundered	Worn No Hole	Worn Hole Beginning	Worn Hole
Poplin Cotton VEE 1110	Permeability $ft^3/min/ft^2$	12.4	13.5	16.2	23.0
	change (%)*		8.9	30.6	85.5
Poplin 50/50 1070A	Permeability $ft^3/min/ft^2$	27.6	44.3	55.6	69.5
	change (%)		60.5	101.5	151.8
Sateen Cotton 727	Permeability $ft^3/min/ft^2$	36.0	62.0	70.6	110.6
	change (%)		72.2	96.1	207.2
Sateen 50/50 1076	Permeability $ft^3/min/ft^2$	10.2	17.9	26.6	47.8
	change (%)		75.5	160.8	368.6
Sateen Cotton (Quarpel) 1109	Permeability $ft^3/min/ft^2$	9.5	11.2	14.3	18.4
	change (%)		17.9	50.5	93.7

* Percentage change based on unworn laundered control.

APPENDIX G

Coefficient of Correlation Computer Program - C-003

1. INTRODUCTION

The computer program summarized in this report was written to compute standard deviations, variances, and the coefficient of correlation for two sets of variables. The program is limited to 100 values for each of the two variables.

2. PROGRAM DESCRIPTION

The program finds the variances (s^2), standard deviation (S), and correlation coefficient (r) through solution of the following equations:

$$(1)\quad \bar{X} = \frac{\Sigma X}{N} \qquad \bar{Y} = \frac{\Sigma Y}{N}$$

$$(2a)\quad S_X^2 = \frac{\Sigma X^2}{N-1} - \frac{(\Sigma X)^2}{N(N-1)} \qquad S_Y^2 = \frac{\Sigma Y^2}{N-1} - \frac{(\Sigma Y)^2}{N(N-1)}$$

$$(2b)\quad S_X^2 = \frac{\Sigma X^2}{N} - \bar{X}^2 \qquad S_Y^2 = \frac{\Sigma Y^2}{N} - \bar{Y}^2$$

$$(3)\quad S_X = \sqrt{S_X^2} \qquad S_Y = \sqrt{S_Y^2}$$

$$(4)\quad r = \frac{\Sigma(XY)/N - \bar{X}\bar{Y}}{S_X S_Y}$$

The value of N can be no greater than 100. Whenever N is less than 40, the variances are computed by Equations (2a); otherwise, Equations (2b) are used. The program reads N and the data and computes the correlation; then it automatically goes on to the next data card to read N and the corresponding data. The progess continues until an "END" card appears in the data to halt the program.

3. OPERATING INSTRUCTIONS

3.1 Deck Make-up

The program is written in WIZ. The object program followed by the deck of data cards is placed behind WIZPAC, and a normal WIZ load is executed. The answers should follow.

3.2 Tape Drives

Not applicable.

3.3 Input

The number of input cards is determined by the amount of data available. The first data card contains one value for N, the number of values for each of the two variables. This card is followed by card(s) containing the data in the following order: x_1, y_1, x_2, y_2, x_3, y_3 --- x_n, y_n. It is imperative that the number of individual readings following N is equal to 2N.

If it is desired to compute more than one correlation, the card containing y_n is followed by another card containing the value N for the second correlation, which is followed by the data as described in the previous paragraph.

The last card containing y_n must be followed by an "END" card.

The values of N and the input data must follow the rules for WIZ data cards.

3.4 Data Display

The output consists of a series of tables, usually on one page. In the first column are a list of values followed by $ X(J); this is a list of the values for the variable X. The list of values for the variable Y is similarly placed in the second column. The third column contains the value of J for each row. Following these tables on the 9 succeeding lines are the values for ΣX, $\bar{X}$, ΣY, $\bar{Y}$, $\Sigma(X^2)$, $\Sigma(Y^2)$, S_X^2, S_Y^2, and $\Sigma(XY)$ respectively. The last line contains S_X, S_Y, and r. A typical output for this program is attached.

4. VARIABLE DICTIONARY

N = J
ΣX = SUMX
$\bar{X}$ = AVX
ΣY = SUMY
$\bar{Y}$ = AVY
$\Sigma(X^2)$ = X SQUARE
$\Sigma(Y^2)$ = Y SQUARE
S_X^2 = VARX
S_Y^2 = VARY
$\Sigma(XY)$ = PRODXY
S_X = SX
S_Y = SY
r = R

```
1.9000000+01 $ X(J)          9.5000000+00 $ Y(J)          -1 $ -J
4.3000000+01 $ X(J)          2.2500000+01 $ Y(J)          -2 $ -J
7.0000000+00 $ X(J)          1.1000000+01 $ Y(J)          -3 $ -J
8.0000000+00 $ X(J)          1.2000000+01 $ Y(J)          -4 $ -J
3.0000000+01 $ X(J)          1.3500000+01 $ Y(J)          -5 $ -J
2.1500000+01 $ X(J)          2.3000000+01 $ Y(J)          -6 $ -J
6.2000000+01 $ X(J)          3.2000000+01 $ Y(J)          -7 $ -J
2.5000000+01 $ X(J)          1.9500000+01 $ Y(J)          -8 $ -J
4.9500000+01 $ X(J)          1.0500000+01 $ Y(J)          -9 $ -J
2.1000000+01 $ X(J)          1.2500000+01 $ Y(J)         -10 $ -J
8.1500000+01 $ X(J)          3.9500000+01 $ Y(J)         -11 $ -J
4.9000000+01 $ X(J)          1.9500000+01 $ Y(J)         -12 $ -J
2.9000000+01 $ X(J)          2.4000000+01 $ Y(J)         -13 $ -J
1.8000000+01 $ X(J)          1.2500000+01 $ Y(J)         -14 $ -J
3.8500000+01 $ X(J)          1.5000000+01 $ Y(J)         -15 $ -J
4.6500000+01 $ X(J)          3.0000000+01 $ Y(J)         -16 $ -J
3.4000000+01 $ X(J)          2.8000000+01 $ Y(J)         -17 $ -J
2.4500000+01 $ X(J)          1.9000000+01 $ Y(J)         -18 $ -J
6.0700000+02 $ SUMX
3.3722222+01 $ AVX
3.5350000+02 $ SUMY
1.9638889+01 $ AVY
2.6654500+04 $ XSQUARE
8.1862499+03 $ YSQUARE
3.6383006+02 $ VARX
7.3170746+01 $ VARY
1.3960000+04 $ PRODXY
1.9074330+01 $ SX      8.5539900+00 $ SY      6.9433348-01 $ R
```

APPENDIX H

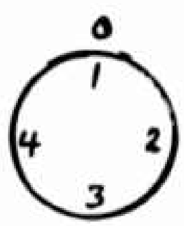
RAW DATA - MASS
(Taber Abrasion)

Abrasion Cycles	Position of Measurement*	Sateen (gms/.111 in^2) x10^3	Oxford (gms/.111 in^2) x10^3
25	0	20.3	13.5
25	1	21.0	13.3
25	2	20.7	13.4
25	3	20.0	13.5
25	4	20.2	13.5
50	0	20.2	13.5
50	1	19.7	13.2
50	2	19.9	13.5
50	3	20.0	13.3
50	4	20.5	13.5
75	0	20.3	
75	1	19.2	
75	2	20.3	
75	3	19.9	
75	4	20.6	
100	0	20.0	13.9
100	1	19.2	13.4
100	2	19.8	13.5
100	3	19.9	13.5
100	4	19.6	13.5
150	0	20.3	
150	1	20.0	
150	2	18.5	
150	3	19.9	
150	4	19.7	
200	0	20.0	13.9
200	1	18.9	12.8
200	2	19.3	13.7
200	3	18.6	13.6
200	4	19.0	13.3
250	0	20.5	13.7
250	1	18.1	13.3
250	2	18.8	13.5
250	3	17.9	13.1
250	4	19.2	13.2

APPENDIX H (cont'd)

Abrasion Cycles	Position of Measurement*	Sateen (gms/.111 in^2) x10^3	Oxford (gms/.111 in^2) x10^3
300	0	20.2	13.5
300	1	16.6	13.2
300	2	17.3	13.3
300	3	17.0	12.9
300	4	17.1	13.2
350	0	19.9	13.9
350	1	15.6	13.5
350	2	16.6	13.2
350	3	15.0	13.2
350	4	18.3	13.6
400	0	20.0	13.6
400	1	15.6	13.0
400	2	14.7	12.0
400	3	16.3	12.9
400	4	12.4	12.2
500	0		13.4
500	1		13.4
500	2		12.5
500	3		12.8
500	4		12.5

*



APPENDIX H (cont'd)

RAW DATA - MASS
(Stoll Abrasion)

Abrasion Cycles	Position of Measurement*	Sateen ($gms/.111\ in^2$) $x10^3$	Oxford ($gms/.111\ in^2$) $x10^3$
50	0	21.2	13.9
50	5	20.7	14.2
100	0	21.6	14.0
100	5	20.8	14.0
200	0	21.2	14.2
200	5	20.3	13.7
300	0	20.7	14.1
300	5	20.2	13.0
400	0		13.6
400	5		13.3
600	0	20.9	13.8
600	5	19.0	12.6
900	0	21.0	
900	5	17.6	
1200	0	20.7	
1200	5	18.1	
1500	0	20.7	
1500	5	16.5	
1800	0	20.5	
1800	5	16.1	
2100	0	21.0	
2100	5	16.2	
2400	0	20.9	
2400	5	16.1	

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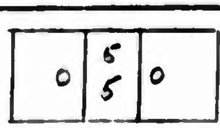

APPENDIX H (cont'd)

RAW DATA - THICKNESS
(Stoll Abrasion)

Abrasion Cycles	Position of Measurement*	Sateen (mils)	Oxford (mils)
50	0	23.3	10.2
50	5	22.8	9.3
100	0	22.9	10.0
100	5	21.5	9.1
200	0	22.7	10.1
200	5	21.5	8.9
300	0	23.0	10.0
300	5	21.2	8.9
400	0		10.0
400	5		8.8
600	0	22.8	10.2
600	5	20.6	8.9
900	0	22.3	
900	5	20.1	
1200	0	22.3	
1200	5	19.0	
1500	0	22.2	
1500	5	18.2	
1800	0	22.3	
1800	5	17.7	
2100	0	22.2	
2100	5	18.0	
2400	0	21.8	
2400	5	18.3	

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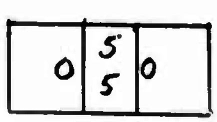
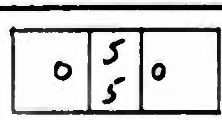


APPENDIX H (cont'd)

RAW DATA - AIR PERMEABILITY
(Stoll Abrasion)

Abrasion Cycles	Position of Measurement*	Sateen (Gurley Seconds/250cc)	Oxford (Gurley Seconds/100cc)
50	0	22.3	52.6
50	5	22.5	66.8
100	0	24.3	56.4
100	5	16.4	65.0
200	0	27.8	58.3
200	5	16.3	66.0
300	0	24.8	55.1
300	5	16.4	70.0
400	0		55.2
400	5		73.5
600	0	26.4	56.6
600	5	10.1	53.5
900	0	27.6	
900	5	8.0	
1200	0	22.3	
1200	5	12.1	
1500	0	27.3	
1500	5	8.3	
1800	0	23.4	
1800	5	6.3	
2100	0	33.1	
2100	5	6.0	
2400	0	27.3	
2400	5	6.2	

*



APPENDIX H (cont'd)

RAW DATA - AIR PERMEABILITY
(Taber Abrasion)

Abrasion Cycles	Position of Measurements*	Sateen (Gurley Seconds/250cc)	Oxford (Gurley Seconds/100cc)
25	0	25.8	41.2
25	1	32.0	50.9
25	2	27.9	54.6
25	3	24.7	59.6
25	4	22.6	59.9
50	0	24.6	47.7
50	1	27.3	58.5
50	2	28.3	67.1
50	3	27.4	62.8
50	4	30.0	68.1
75	0	26.7	
75	1	25.8	
75	2	32.5	
75	3	27.0	
75	4	34.2	
100	0	30.2	43.5
100	1	24.6	89.2
100	2	25.0	81.9
100	3	35.0	84.1
100	4	27.8	84.1
150	0	27.4	
150	1	32.4	
150	2	23.2	
150	3	32.8	
150	4	27.0	
200	0	30.0	47.1
200	1	28.4	119.2
200	2	27.7	114.7
200	3	26.7	129.1
200	4	27.2	94.6
250	0	29.2	44.5
250	1	25.5	143.3
250	2	34.0	119.0
250	3	27.4	135.8
250	4	32.5	115.0

APPENDIX H (cont'd)

Abrasion Cycles	Position of Measurements*	Sateen (Gurley Seconds/250cc)	Oxford (Gurley Seconds/100cc)
300	0	27.2	42.7
300	1	20.4	126.0
300	2	24.0	124.5
300	3	22.0	131.2
300	4	26.5	105.7
350	0	26.4	
350	1	14.5	
350	2	24.1	
350	3	12.8	
350	4	23.1	
400	0	25.3	44.5
400	1	6.7	195.7
400	2	14.6	122.5
400	3	10.0	159.0
400	4	18.2	117.8
500	0		45.1
500	1		177.8
500	2		147.7
500	3		186.6
500	4		127.0

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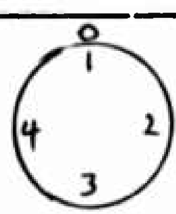


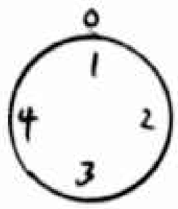
APPENDIX H (cont'd)

Abrasion Cycles	Position of Measurement*	Sateen (mils)	Oxford (mils)
25	0	22.0	10.1
25	1	21.8	10.0
25	2	21.1	10.3
25	3	21.6	10.0
25	4	21.2	10.7
50	0	21.7	10.1
50	1	21.6	10.1
50	2	21.6	10.5
50	3	21.7	9.8
50	4	21.3	10.7
75	0	21.9	
75	1	21.1	
75	2	21.6	
75	3	21.6	
75	4	21.2	
100	0	21.9	10.6
100	1	21.1	10.6
100	2	20.8	11.1
100	3	21.5	10.2
100	4	21.0	10.8
150	0	21.9	
150	1	22.0	
150	2	20.5	
150	3	21.7	
150	4	20.8	
200	0	21.7	10.5
200	1	21.2	9.7
200	2	21.2	10.5
200	3	20.5	10.0
200	4	20.8	10.1
250	0	21.7	10.4
250	1	20.3	10.1
250	2	20.5	10.3
250	3	21.0	9.8
250	4	21.2	10.5

APPENDIX H (cont'd)

Abrasion Cycles	Position of Measurement*	Sateen (mils)	Oxford (mils)
300	0	21.8	10.2
300	1	20.1	9.9
300	2	19.9	10.1
300	3	20.1	9.9
300	4	19.8	10.2
350	0	21.9	10.6
350	1	19.2	10.1
350	2	19.0	10.6
350	3	18.6	9.7
350	4	20.0	10.3
400	0	22.0	10.4
400	1	17.2	9.5
400	2	19.9	9.7
400	3	19.0	9.6
400	4	19.8	9.6
500	0		10.4
500	1		9.2
500	2		9.8
500	3		9.6
500	4		9.7

*



APPENDIX I

Application of the χ^2 Technique to Show Significance of Differences Between Face and Back Abrasion

x_1 Face	x_2 Back	$x_1 - x_2$
343.4	333.0	+
400.0	387.5	+
491.0	459.1	+
442.8	396.5	+
601.2	582.5	+
774.5	735.0	+
586.0	597.7	-
590.3	810.0	-
291.4	288.7	+
318.7	310.0	+
396.7	379.0	+
386.0	371.2	+
476.5	481.5	-
472.5	465.5	+
620.0	586.3	+
532.5	484.5	+
326.5	331.7	-
342.8	344.2	-
440.0	439.0	+
440.8	431.0	+
594.3	573.6	+
616.5	597.0	+
702.2	690.6	+
790.7	726.2	+
288.7	306.0	-
332.4	325.7	+
362.8	365.5	-
369.1	353.5	+
441.3	424.5	+
461.5	448.2	+
513.1	521.2	-
512.4	482.4	+

Total = 32

24 greater

8 less

	f obs	f_c exp	$f-f_c$	$(f-f_c)^2$	$\frac{(f-f_c)^2}{f_c}$
greater	24	16	+8	64	4.0
less	8	16	-8	64	4.0
total	32	32			8.0

$n = 1$

This value of χ^2 is between the .01 and the .001 level of probability and thus the differences are clearly significant.

APPENDIX J

Computation of Modified Exponential Equations for Oxford Fabrics

-First Oxford-

Basic Exponential

Cycles of Abrasion (C)	Air Permeability (A)	A-1.6	log (A-1.6)
0	6.9	5.3	.7243
50	4.8	3.2	.5052
100	3.6	2.0	.3010
200	2.7	1.1	.0414
300	2.5	.9	-.0458
400	2.1	.5	-.3010
500	1.9	.3	-.5229

Equation of Basic Exponential by Method of Averages for Linear Points

C	log (A-1.6)
0	.7243

	C	log (A-1.6)
	50	.5052
	100	.3010
2	150	.8062
	75	.4031

$$\log (A-1.6) = \log a + \frac{b}{2.3}C$$

$$.7243 = \log a + o$$

$$\log a = .7243 \qquad a = 5.3$$

$$.4031 = .7243 + \frac{b}{2.3}75$$

$$.4031 - .7243 = \frac{b}{2.3}75$$

$$-.3212 = \frac{b}{2.3}75$$

$$b = -.00983$$

APPENDIX J (cont'd)

Solutions by Residuals

$$(A-1.6) = 5.3e^{-.00983C} + r$$

r = residual

$$r = (A-1.6) - 5.3e^{-.00983C}$$

C	A-1.6	$5.3e^{-.00983C}$	r
200	1.1	5.3 x .14 = .74	.36
300	.9	5.3 x .052 = .276	.52
400	.5	5.3 x .02 = .106	.39
500	.3	5.3 x .007 = .037	.26

Equation of Residual by Method of Averages

C	log r
200	.2648
300	.0719
2 | 500	.3367
250	.1684

C	log r
400	-.2147
500	-.4685
2 | 900	-.6832
450	-.3416

$$.1684 = \log a + \frac{b}{2.3}\,250$$

$$-.3416 = \log a + \frac{b}{2.3}\,450$$

$$.5100 = -\frac{b}{2.3}\,200$$

$$b = -.00586$$

$\log a =$

$$\log a = .1684 - \frac{b}{2.3}\,250$$

$$\log a = .1684 + .637$$

$$\log a = .8054$$

$$a = 6.4$$

$$r = 6.4e^{-.00586C}$$

APPENDIX J (cont'd)

Equation of Residual by Averaging

$$r_1 = .36$$
$$r_2 = .52$$
$$r_3 = .39$$
$$r_4 = \underline{.26}$$
$$r_{\bar{x}} \quad .38$$

$$A-1.6 = 5.3e^{-.00983C} + .38$$
$$\text{or } A = 5.3e^{-.00983C} + 1.98$$

Equation of Residual by Minimizing Differences

Values of Air Permeability

Experimental	C = 1.98	C = 1.8	C = 1.7	C = 1.6
6.9	7.3	7.1	7.0	6.9
4.8	5.2	5.0	4.9	4.8
3.6	4.1	3.8	3.8	3.7
2.7	2.7	2.5	2.4	2.3
2.5	2.5	2.3	2.2	2.1
2.1	2.4	2.2	2.1	2.0
1.9	2.2	2.1	2.0	1.9
Dev $\bar{x}$ (Ignoring sign)	.27	.18	.16	.14

Final equation based on selection of residual which minimized differences is $A = 5.3e^{-.00983C} + 1.6$

–Second Oxford
(Omitting data point for 300 cycles)

Cycles of Abrasion (C)	Air Permeability (A)	A-1.5	log (A-1.5)
0	3.51	2.01	.3032
50	2.96	1.46	.1644
100	2.63	1.13	.0531
200	2.17	.67	- .1739
400	1.74	.24	- .6198
500	1.58	.08	-1.0969
600	1.52	.02	-1.6990
700	1.51	.01	-2.0000

APPENDIX J (cont'd)

Equation of Basic Exponential by Method of Averages for Linear Points

	C	log (A-1.5)
	0	.3032
	50	.1644
	100	.0531
3	150	.5207
	50	.1736

	C	log (A-1.5)
	200	-.1739
	200	-.1739
	400	-.6198
2	600	-.7937
	300	-.3969

$$\log (A-1.5) = \log a + \frac{b}{2.3} C$$

$$.1736 = \log a + 50\left(\frac{b}{2.3}\right)$$

$$-.3969 = \log a + 300\left(\frac{b}{2.3}\right)$$

$$.5705 = -250\left(\frac{b}{2.3}\right)$$

$$b = -.00524$$

$$.1736 = \log a + 50\ (-.00228)$$

$$\log a = .1736 - 50\ (-.00228)$$

$$\log a = .1736 + .1140 = .2876$$

$$a = 1.94$$

$$A-1.5 = 1.94e^{-.00524C}$$

Solution by Residuals

$$A-1.5 = 1.94e^{-.00524C} - r$$

$$r = 1.94e^{-.00524C} - (A-1.5)$$

C	A-1.5	$1.94e^{-.00524C}$	r
500	.08	.073 x 1.94 = .142	.062
600	.02	.043 x 1.94 = .083	.062
700	.01	.025 x 1.94 = .049	.039

APPENDIX J (cont'd)

Since the above data did not plot linearly the "r" value was determined by averaging.

$$\begin{array}{r} .062 \\ .062 \\ \underline{.039} \\ \bar{x} = .05 \end{array}$$

$$\text{then } A-1.5 = 1.94e^{-.00524C} - .05$$

$$\text{and } A = 1.94e^{-.00524C} + 1.45$$

-Second Oxford-

(including data point for 300 cycles)

Basic Exponential

Cycles of Abrasion (C)	Air Permeability (A)	A-1.5	log (A-1.5)
0	3.51	2.01	.3032
50	2.96	1.46	.1644
100	2.63	1.13	.0531
200	2.17	.67	- .1739
300	2.24	.74	- .1308
400	1.74	.24	- .6198
500	1.58	.08	-1.0969
600	1.52	.02	-1.6990
700	1.51	.01	-2.0000

APPENDIX J (cont'd)

Equation of Basic Exponential by Method of Averages for Linear Points

C	log (A-1.5)
0	.3032
50	.1644
100	.0531
3 ⌊150	.5207
50	.1736

C	log (A-1.5)
200	-.1739
300	-.1308
400	-.6198
3 ⌊900	-.9245
300	-.3082

$$\log (A-1.5) = \log a + \frac{b}{2.3} C$$

$$.1736 = \log a + 50\left(\frac{b}{2.3}\right)$$

$$-.3082 = \log a + 300\left(\frac{b}{2.3}\right)$$

$$.4818 = -250\left(\frac{b}{2.3}\right)$$

$$\frac{b}{2.3} = -\frac{4818}{250} = -.00193$$

$$b = -.00444$$

$$.1736 = \log a + 50\ (-.00193)$$

$$\log a = .2701$$

$$a = 1.86$$

$$A-1.5 = 1.86e^{-.00444C}$$

The residual in this case would be equivalent to that obtained with the data including the 300 cycle point.

Unclassified

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3. REPORT TITLE MASS, PERMEABILITY, AND THICKNESS CHANGES IN ABRADED FABRICS	
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Fabric Engineering & Finishing Branch Clothing & Organic Materials Division U.S. Army Natick Labs., Natick, Mass.

13. ABSTRACT

This report presents the changes that take place in mass, permeability, and thickness during the abrasion of textile fabrics. Changes in permeability are shown to be influenced by the extent to which the abraded fabric will retain fiber debris during the course of the abrasion. While the permeability of a cotton oxford fabric decreases continuously and significantly up to the point of hole formation, the permeability of a sateen fabric increases during abrasion, an effect which is normally expected as a result of breakdown in the yarn structure. The extent to which the fiber debris is retained by the fabric is a function of the rate of loss of mass. Thickness decreases are a function more of the type of abrader than of the type of fabric. Changes in permeability as well as in thickness are not simple functions of the degree of abrasion of all fabric types; they must be viewed in terms of the response of specific fabrics to specific types of abrasive action.

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Abrasion	6		9			
Textiles	1,9		9			
Cotton textiles	1,9		9			
Mass	7					
Permeability	7					
Thickness	7					
Measurement			8			

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